Wageningen University and Re:

Winand Staring Centre for Integrated Land, Soil and Wat

Effects of acid atmospheric deposition on the chemical composition of loess, clay and peat soils under forest in the Netherlands

J.M. Klap, W. de Vries en E.E.J.M. Leeters

ALTERRA
GREEN WORLD RESEARCH

REPORT 97
Wageningen, 1999

Effects of acid atmospheric deposition on the chemical composition of loess, clay and peat soils under forest in the Netherlands

J.M. Klap
W. de Vries
E.E.J.M. Leeters

Report 97

Winand Staring Centre, Wageningen (The Netherlands), 1999

ABSTRACT

Klap, J.M., W. de Vries & E.E.J.M. Leeters, 1999. *Effects of acid atmospheric deposition on the chemical composition of loess, clay and peat soils under forest in the Netherlands.* Wageningen (The Netherlands), Winand Staring Centre. Report 97. 182 pp.; 3 Figs; 102 Tables; 66 Refs; 5 Annexes.

In addition to a survey of the soils under 150 forest stands on non-calcareous sandy soils, the chemical composition of the soils under 40 stands on non-calcareous loess soil, 30 stands on non-calcareous clay soils and 30 stands on oligotrophous peat soils have been examined, to assess the current status with repect to acidification and eutrophication, and the provide data for further studies. Only the clay soils are not yet seriously affected by the atmospheric inputs. The loess soils are generally considerably acidified, except the alluvial loess soils. The peat soils show a considerable eutrophication, especially in the topsoil, whereas anthropogenic acidification can hardly be separated from their natural acidity. Most investigated heavy metals show elevated concentrations, both in the humus layer and in the top soil, but serious pollution is not found.

Keywords: acid deposition, acidification, critical loads, eutrophication, exchangeable cations, field data, heavy metals, nutrients

P.O. Box 125, NL-6700 AC Wageningen (The Netherlands).
Phone: 31 317 474 200; fax: 31 317 424 812; e-mail: postkamer@sc.dlo.nl

ALTERRA is the amalgamation of the Institute for Forestry and Nature Research (IBN) and the Winand Staring Centre for Integrated Land, Soil and Water Research (SC). The merger will take place on 1 Januari 2000.

Projects 7160 (Rep97.IS/06-99)

Contents

Preface

Soil acidification research conducted within the Dutch Priority Programme on Acidification has greatly increased our knowledge about the impact of atmospheric deposition on non-calcareous sandy forest soils. However, information on the impact on non-sandy forest soils is largely lacking until now. Here we report the results of a survey of the chemical soil and soil solution composition below 100 forest stands on loess, clay and peat soils. In order to generalize the collected data, they have been used to calibrate a regional soil acidification model and to assess the impact of various scenarios on the chemistry of these forest soils (Van der Salm et al., 1998; Van der Salm & De Vries, 1998).

One of the aims was to gain insight in the regional variability of chemical parameters and its relationship with deposition level, tree species, stand and site characteristics. Furthermore, the results of this study whould provide the baseline data for further scientific research. This includes both fundamental research and research to support policy making, e.g. with respect to abatement strategies for air pollution and the protection of the natural environment, as worked out in national environmental policy plans (NMP, 1989; NMP-Plus, 1990), the annual 'State of the Environment' (Milieubalans, 1995-1998) and the national policy plan for nature protection (NBP, 1990; Natuurbalans, 1998). This research was financially supported by the Dutch Ministry of Agriculture, Nature Management and Fisheries (LNV), the Dutch Ministry of Housing, Physical Planning and Environment (VROM), and the European Commission (DG VI).

All the work included was carried out by SC-DLO, including field work, chemical analyses and reporting, except a few chemical analyses, which were carried out by BLGG (Oosterbeek). The publication of the results of this assessment has been delayed by the competition of more urgent projects, whereas the processed date were already available for further use.

We thankfully acknowledge all the colleagues who assisted in site characterisation and soil sampling, i.e. D.J. Groot Obbink, H. Van het Loo, R. Visschers, J.G. Vrielink and R. Zwijnen, in pre-treating and analyzing the various soil samples, i.e. W. Balkema, L.C. Van Liere, M.M.T. Meulenbrugge and R.Ch. Sjardijn and in data processing, i.e. J.C.H. Voogd. We also thank the owners of the various forest complexes for giving us consent to take samples on their properties.

The authors

Summary

Background and aims

Soil acidification research in the Netherlands conducted so far has greatly increased our knowledge about the present impact of atmospheric deposition on non-calcareous sandy forest soils. Extensive research has been conducted on the chemical composition of the humus layer, the mineral soil and the soil solution of 150 forest locations on non-calcareous sandy soils (De Vries & Leeters, 1999). However, until now the sites that were studied did not include non-sandy soils, such as loess, clay and peat soils.

In order to overcome the limitation caused by this lack of information an assessment has been made of the chemical composition of the humus layer[1)], mineral (top) soil and soil solution of 40 forest stands on loess and loess-related soils, 30 stands on clay soils and 30 stands on peat soils in the Netherlands. The locations on loess and clay soils were limited to the non-calcareous soils, whereas the peat soils were limited to the oligotrophic peat soils.

The major aims of this assessment were to

- give an overview of the chemical soil composition (buffer capacity and N-enrichment) and soil solution chemistry (acidification status) of non-calcareous loess, clay and peat soils in the Netherlands;
- give insight in the relationship between the chemical composition of humus layer, mineral soil and soil solution with deposition level, stand characteristics and site characteristics;
- provide data for further use in model simulations to predict long term impacts of the deposition of nitrogen and acidity on these forest soils.

The results related to the first two aims are presented in this report, whereas the results of the third aspect are reported separately (Van der Salm et al., 1998)

Methods

The loess soils have been sampled in the period March to April 1992 and the clay and peat soils one year later. Samples have been taken from the humus layer and from four mineral layers: 0-10 cm, 10-30 cm, 30-60 cm and 60-100 cm. The mineral samples consisted of 20 subsamples and the humus samples of 10 subsamples. The results for the solid phase for the four mineral layers haven been analysed in combination. The same has been done for the results for the soil solution in these four layers. The results for the humus layer have been analysed separately.

The chemical composition of both the solid phase (texture, contents of organic matter, C, N and P, CEC and exchangeable H, Al, Fe, Ca, Mg, K, Na and NH_4 and oxalate extractable P, Al and Fe) and the soil solution (pH and concentrations of H, Al, Fe, Ca, Mg, K, Na, NH_4, NO_3, SO_4, Cl and RCOO) was analyzed in all mineral layers,

1) The term 'humus layer' is used here as a compound for the complete ecto-organic soil profile, including the L (litter), F (fermentation) and H (humus) horizon.

except for the soil solution of the mineral soil layer 30-60 cm of the loess soils. If a humus layer was present, the chemical composition was analyzed (thickness, contents of organic matter, C, N, P, K, Ca, Mg, S, Pb, Cd, Cu, Zn, Ni and Cr, CEC and exchangeable H, Al, Fe, Ca, Mg, K, Na and NH_4).

All results have been related to (a selection of) deposition characteristics (N and acidity), stand characteristics (tree species, tree height and canopy coverage), positional characteristics (distance to, direction of and kind of surrounding land use) and site characteristics (soil type and drainage class). The results for the loess, clay and peat soils were compared with those obtained for the sandy soils (De Vries & Leeters, 1999).

Results of the humus layer
The **thickness** of the humus layer decreased from sandy soils > loess soils > peat soils > clay soils. On most clay soils hardly any humus layer was observed, due to the rapid decomposition on these rich soils covered with a poplar stand. Within the loess and peat soils the thickness (and pools) vary as a function of the soil type, which also determines the pools of the various variables determined in the humus layer. With median values of 2.5% in the organic matter, the **N contents** in the humus layer of loess and peat soils was slightly higher than for the sandy soils. The variation in N content is mainly determined by the soil type and the tree species, but also a relationship is suspected (accumulation of deposited N). The **contents of P, Ca, Mg and K** generally increased from peat soils < sandy soils < loess soils. Also within the loess and peat soils the contents of these elements showed an increase from the more vulnerable soil types to the less vulnerable soil types.

The **pH** values for most loess and peat soils are approximately 0.5 unit higher than for the sandy soils. Considerable higher pH values are found the fluvial loess soils and under 'Other Deciduous Species' on loess soils. The **CEC** (of the organic matter) decreased from loess soils > sandy soils > peat soils. The results vay as a result of the soil type and the tree species. These difference can partly be explained by the influence of the pH on the CEC. The **base saturation** for the loess and peat soils (ca. 66%) is approximately two times as high as for the sandy soils, whereas the values for the **H and Al occupation** are approximately half of the values for the sandy soils. The results vary as a function of the soil type and the tree species.

The **heavy metal contents** decreased from sandy soils > loess soils > peat soils for Pb, Cu and Ni, and increased in this order for Zn and Cd. The contents of Pb, Zn and Cd are slightly elevated above the natural background level and some results for Zn are even moderately elevated.

Results of the mineral soil
The **organic matter contents** of the mineral parent materials increases from sandy soils < loess soils < clay soils. The organic matter contents decreases with depth for the loess and clay soils. The organic matter content of the peat soils varies as a function of soil type and depth. In general an increase is found for the **N and P contents** (of the organic matter) and P pools: peat soils < sandy soils < loess soils < clay soils and a decrease in C/N in this order. The N contents and pools and the C/N ratio decrease with depth for all soil types. The results correlate well with the deposition estimates. The results

indicate that considerable accumulation of N has taken place, thus cuasing nutrient inbalances on nutrient poor soil types.

The **pH values** increase from peat soils + sandy soils < loess soils < clay soils. In general the pH values increased with the depth. Most clay soils and the fluvial loess soils are in the upper end of the cation exchange buffer range. Most loess soils are at the lower end of the cation exchange buffer range. The pH values increase with depth for the loess and peat soil and decrease for the clay soils. The observed variation seems also to correlate with the deposition estimates, besides the soil type. The **CEC** of the is determined by the organic matter content (and the pH), for all observed soil types, and with the clay contents in the loess and clay soils. The CEC of the clay is considerably less effective for loess soils than for 'regular' clay soils. The **base saturation** decreased from clay soils > peat soils > loess soils > sandy soils. All observed soil types in loess and peat seem to be affected by anthropogenic acidification, except, possibly, the peat soils in the low moor area and fluvial loess soils. The fluvial loess soils and the medium-textured clay soils form a group which might be affected at the middle-long term.

The **Al_{ox}, Fe_{ox} and P_{ox} contents** decrease from clay soils > loess soil > peat soil > sandy soils and, generally decreased with depth. The pools for peat soils are, however, much smaller than for sandy soil. Within the three groups, contents and pools generally increase with the expected decrease in vulnerability to acidification.

The **total contents of minerals and heavy metals** are generally related to the soil type, especially as expressed in the differences in clay content. The heavy metal content is generally slightly elevated for Pb (all soil types) and for Cu, Zn, Ni and Cr (in the clay soils). A relationship with atmospheric deposition can not be proven. No seriously polluted sites were found.

Results of the soil solution

The **pH values** in the soil solution decreases from clay soils > loess soils > sandy soils > peat soils, and generally increases with depth. This order reflects the similar order for the pH(H_2O) and the pH(KCl).

For the **loess soils**, the soil solution composition indicates that most of these soils are considerably affected by the deposition of N (and S) compounds, as manifested in the high NO_3, SO_4 and Al concentrations and high Al/Ca, NH_4/Mg and (NH_4+NO_3)/SO_4 ratios. The low NH_4 concentrations indicate, however, that nitrification is not hampered. Within the loess soils, the fluvial soils are far less affected by the atmospheric deposition, due to the large available buffer capacity of exchangeable cations and (at some locations) of carbonates.

For the **clay soils**, the soil solution does not indicate that these soils are adversely affected by atmospheric deposition. The pH values and the Ca and Si concentrations indicate that these soils are well buffered by the initial stage of the cation exchange buffer and for some locations even still by the carbonate buffer. The inputs of NH_4 are quickly nitrified and successively taken up or, especially in the wet soils denitrified. Only the topsoil of medium textured soils under beech or oak, seem to be affected, as indicated by the Al and NH_4 concentrations and the NH_4/K ratio.

For the **peat soils**, the soil solution indicates that the input of acidity is mainly buffered by the release of (exchangeable) base cations and locally by base cations from surface or seepage water. Although most peat soils have very low pH values, the Al concentrations are low, which is mainly due to the little amount of easily weatherable Al containing minerals. Atmospheric input of acidy is mainly buffered by cation exchange and in the low moor area also by the availability of base cations from nearby mesotrophic surface water. The high NH_4 concentration indicate the nitrification might be hampered, whereas the low NO_3 concentrations indicate that denitrification plays an important role, except in the very topsoil and at the driest and most earthified locations. Denitrification might have a significant share in the buffering of acid deposition. Shallow water-tables and good groundwater quality (low N concentrations, moderate base cation concentrations) might be important factor in counteracting adverse effects of atmospheric deposition.

Conclusions and recommendations

The general conclusions about the chemical composition of the loess, clay and peat soils, with respect to the acidification and eutrophication status and the most important determining environmental characteristics, are:

- There is no evidence that the thickness and pool of the humus layer on the loess, clay and peat soils is affected by atmospheric deposition. Soil type and tree species are the dominant determinants.
- Most non-calcareous loess soils are moderately acidic, and should be considered as highly vulnerable for further acidification. The fluvial loess soils and the medium-textured clay soils are vulnerable for acidification at the longer term. The fine-textured clay soils are not acidified and also not vulnerable for acidification. Most peat soils are naturally acidic, and anthropogenic acidification can hardly be separated from the natural acidity and natural acidification.
- Most loess and peat soils are considerably affected by the continuous deposition of nitrogen. Especially the nutrient poor soil types show excess N values and the risk of induced deficiencies of other elements. The fluvial loess soil are less vulnerable, due to the higher availability of other elements, like the clay soils. The peat soils in the low moor area are less vulnerable, mostly due to the water-logged conditions in most of these soils. The eutrophication in the peat soils in the high moor area might be worsened by mineralisation related to excess drainage. The effects are most distinct in the topsoil and the humus layer.
- Slightly elevated heavy metal contents are found in the humus layer, especially for the elements with atmospheric inputs (Pb, Cd and Zn). Slightly elevated heavy contents in the topsoil (0-10 cm) are mainly found in the clay soils. Serious pollution with heavy metals was not found in any of the sampled locations.

The following conclusions can be drawn with respect to the usefulness of the collected data for further studies:

- The data provide consistent and representative sets of values for the chemical composition of loess, clay and peat soils under forests in the Netherlands.
- The data for the soil solution are representative for the years in which the soils were sampled, but are less representative for other years. These data may be useful as initial values in scenario studies or for validation purposes.
- The data for the mineral soil and for the humus layer can be considered as useful

values for a longer period of time (several years) and can thus be used as fixed values in certain scenario studies.

- There are certain limitations in the applicability of the data, due to the strict selection criteria: no reliable estimates can be provided for calcareous soils (loess and clay), maritime clay soils and real low moor peat soils.
- For most investigated variables, the set of 'universally available' stand and site characteristics (i.e. soil type, drainage class and tree species) can provide reasonable estimates. There are, however, also many correlations with environmental characteristics that are not easily available for scenario and upscaling studies.
- The estimated coefficients for the relevant stand and site characteristics may improve considerably by combining the data for the three observed soil types here and also the sandy soils. Even the soil types that are now still missing could then be included.

1 Introduction

1.1 Background and aims

Soil acidification research in the Netherlands conducted so far has greatly increased our knowledge about the present impact of atmospheric deposition on non-calcareous sandy forest soils. However until now the sites that were studied did not include non-sandy soils, such as loess, clay and peat soils. The Dutch Priority Programme on Acidification was particularly focused on non-calcareous sandy soils, covered with Douglas Fir (e.g. Heij & Schneider, 1991). Further investigations on the spatial variability of soil and soil solution composition and the relationships with forest vitality characteristics were also limited to the non-calcareous sandy forest soils (De Vries & Leeters, 1999; Hendriks et al., 1994; Jansen & De Vries, 1994; Leeters et al., 1994).

The restriction of our knowledge to non-calcareous sandy soils appeared to be a major limitation in a nation-wide assessment (and mapping) of the vulnerability of forest soils in the Netherlands for acidification and eutrophication (De Vries et al., 1989). Not enough data were available to make an extrapolation to non-sandy soils. The most important shortcomings were the lack of information on the exchangeable base cation content (to establish the remaining acid buffer capacity) and on N related parameters, such as the C/N ratio (in order to establish the eutrophication status).

In order to overcome the limitation caused by this lack of information an assessment has been made of the chemical composition of the humus layer[1)], mineral (top) soil and soil solution of 40 forest stands on loess and loess-related soils, 30 stands on clay soils and 30 stands on peat soils in the Netherlands.

The major aims of this assessment were to
1. give an overview of the chemical soil composition (buffer capacity, N-enrichment and heavy metals) and soil solution chemistry (acidification status) of non-calcareous loess, clay and peat soils in the Netherlands;
2. give insight in the relationship between the chemical composition of humus layer, mineral soil and soil solution with deposition level, stand characteristics and site characteristics;
3. provide data for further use in model simulations to predict long term impacts of the deposition of nitrogen and acidity on these forest soils.

The results related to the first two aims are presented in this report. More detail is given in section 1.3. The results of the model simulations are covered in two scientific articles (Van der Salm et al., 1998; Van der Salm & De Vries, 1998).

---

1) The term 'humus layer' is used here as a compound for the complete ecto-organic soil profile, including the L (litter), F (fermentation) and H (humus) horizon.

1.2 Forests on loess, clay and peat soils

1.2.1 Loess soils

The forests on loess soils can be divided (according to the different types of loess and loess-related soils in the Netherlands) in (i) the forests of the Southern Limburg hill landscape, where extensive loess layers occur, and (ii) the forests of the sheltered sides of the ice-pushed ridges of Northern Limburg (near Nijmegen) and the South-East Veluwe, where only discontinuous areas with loess deposits are found. Besides, there are also (iii) forests of the river valleys within the Dutch loess area, where the soils are predominantly loess-like (loess-derived) (Vleeshouwer & Damoiseaux, 1990; Van den Broek & Breteler, 1970; Vink, 1949; Mücher, 1973; Van den Akker & Poelman, 1976). Annex A.1 gives a more extensive treatise of the geography, geogenesis and pedogenesis of loess and loess-related soils in the Netherlands, the differences among the different types and their relevance for soil chemistry and forest ecology.

The most typical and most extensive type of forest on loess (and loess-related) soils is the so-called 'hill-side forests' (Dutch: *hellingbossen*) in Southern Limburg (Fig. 1). This is the only part of the Netherlands with a more or less continuous loess cover. This cover is a part of a vast area covered with loess, which stretches out far more east in Germany and south in Belgium. The northern boundary of this loess belt in the Netherlands is roughly located north of the village of Sittard. However, in the hilly country of Southern Limburg the forest area is mostly limited to steep slopes. The flat areas (which have the most extensive and thickest loess layers in this region) have only few forest. These areas have been occupied since long ago by agricultural land.

Although covered with forest, the lands on these slopes were used intensively for agricultural use during many centuries. The very frequent cutting of the woods was common use, resulting in coppice, coppice with stand-overs or even in almost tree-free 'wastelands'. The hill side forests were also used for grazing cattle. Some of the resulting vegetation types had a very rich (herb) species composition (e.g. with many rare orchid species). Only recently (since the 1950's) management has turned towards the more usual practice of forestry. Some expansion of the forest area has taken place on the slopes and plateau edges.

Especially on the steep slopes, which are now covered by forest, the original loess layer has been eroded partly and mixed up with underlying materials, resulting in a number of typical zonation of soil types with a more or less clear loess-like character (cf. Annex A.1) and in loess-like colluvial soils at the bottom of the hills and in filled-up valleys. The loess soils of the plateau edges are considered to be primary sediment, although the typical Luvisol profile is often fully or partly eroded.

The forests on loess of Northern Limburg and the South-East Veluwe are mostly parts of larger forest areas (Fig. 2). They are both situated on the sheltered south-east exposed side of high ice-pushed ridges, which are mainly covered with forest. Most of these forests have been managed regularly for at least one century. The soils of these ridges themselves consist of sandy or gravelly deposits. The chemical composition of these soils has been investigated earlier (De Vries & Leeters, 1999).

The forests in the river valleys mainly occur on soils which are often strongly influenced by the re-sedimentation of loess (secondary loess soils, either colluvial or alluvial). Most of these forests occur in single stands or in small forest complexes in the valleys of the river Geul and the lower terraces in the wide valley of the river Meuse. There are hardly any extensive forest areas in this region. The forests on the lowest terrace of the river Meuse and in the Roer valley, which also contain amounts of loess-derived material, are included in the clay soils (Section 1.2.2).

1.2.2 Clay soils

Only a small part of the clay soil area in the Netherlands is covered by forest. This counts both the marine and the fluvial clay soils (Fig. 1 and 2). Besides most of the marine clay soils and a considerable part of the fluvial clay soils contain significant amounts of carbonates (cf. Annex A.2), which makes them almost invulnerable for acidification. Therefore, the calcareous clay soils are not taken into account (cf. Section 2.1).

Most of the clay soils are excellent grounds for several forms of agriculture, and therefore not much ground was left over for forests. However, in the backswamp areas of the central river plain in the Netherlands agricultural use was limited to grass land and some forest land because of excess of water and poor tillability. For long, the most important forests in these areas were coppice and other farmer's woods. Coppice lots occurred either in connection with duck-decoys or as separate farmer's coppice lots. The main species used in the holm field is Willow, but Ash and Alder occur as well.

In some areas, like the 'Oude Rijn' area near Utrecht, garden forests of (former) castles and mansions contribute considerably to the total area of old forest on clay soils. Usually, these castles have been built on the natural levees, with the gardens stretching into the nearby backswamp area. The variety in texture, carbonate content and hydrology within these forests, combined with the intensive management and the artificial input of rare species cause that these mansion forests often have a very rich vegetation. The tree layer may be composed of a great variety of deciduous tree species and the herb layer is mostly very rich in species indicating the favourable nutrient and moisture conditions. The old mansion forests on clay soils mainly occur on fluvial clay soil and often contain the gradient from calcareous natural levees towards in non-calcareous backswamp conditions.

Only recently the area of forests on clay soils has expanded more rapidly. Many scattered poplar stands and some little forests have been planted, both in the fluvial floodplain and in the marine clay soil areas. This happened mostly after drainage and re-allotment many of the coppice lots have been planted in with poplar. The young stands can easily be distinguished from the older ones by the usual dominance of Stinging Nettle (*Urtica dioica*) in the herb layer. These little forests occur throughout the fluvial and marine clay area, both on calcareous and non-calcareous clay soils. However, the greatest expansion of the forest area on clay soils has taken place in the young marine clay area. In the more recent polders like the Haarlemmermeer Polder (a drained lake) and the Zuiderzee Polders, large forest areas have been planted, both for wood production and recreational purposes. These forests usually form large continuous forest areas. They contain stands of many different deciduous tree species, with a limited number of coniferous stands. However, these forests occur almost exclusively on calcareous clay soils. The spatial distribution of calcareous and non-calcareous marine clay soils and the calcareous and non-calcareous fluvial clay soils highly determines the distribution of the forest investigated in this project. For the marine clay soils this distribution depends on the age of the soil and its position above or below sea level, whereas for the fluvial clay soils this distribution mainly depends on the position with regard to the river (cf. Annex A.2).

1.2.3 Peat soils

The original peat lands in the Netherlands did not carry much forests and the area of peat soils in the netherlands once was much larger than the present area of peat soil. The area of peat soils in the Netherlands has decreased considerably since man finally started to colonize all grounds that were badly accessible before. In the Netherlands two major types of peat areas are distinguished: high moor peat areas and low moor peat areas. Low moor occurs in the area below (sometimes just above) sea level in the western, north-western and northern part of the country, while high moor occurs in more elevated areas in the south-eastern, eastern and north-eastern parts of the country. The differences of these two types are mainly related to former and present land use and to the former and present hydrological conditions (cf. Annex A.3).

The greater part of both the low moor area and the high moor area consisted of raised bogs. Those raised bogs were too oligotrophic and too wet for the growth of trees. Tree growth was only possible in case of the nearby presence of occasionally flooding streams, the presence of seepage water (in the low moor area) or the presence of a mineral subsoil at a shallow depth (in the high moor area). Both the area of peat soils and the growing conditions for trees on the remaining peat soils have been changed very much since then, due to cutting of peat and drainage.

In the high moor area most of the remaining peat soils have been drained, sometimes excessively. This drainage caused the acceleration of the decomposition rate of the organic matter, which subsequently increased the availability of nutrients. Therefore, many parts of the non-cut-over and partly cut-over peat areas have been afforested with many different tree species. Depending on the depth of drainage, the properties of the peat and the tree species, growth of these forests can be moderate to very good. Other parts have been covered spontaneously with forest. Birch is the most common (sometimes only) tree species on the wet and very wet sites. On deeper drained sites also other species, like oak and Scots pine, occur spontaneously. Only extremely wet sites are not covered spontaneously with forest or carry some scattered lamentable birches.

In the low moor area the original raised bog peat soils have almost disappeared. Only the more eutrophic parts of the peat were left over. The remaining parts are relatively rich in nutrients, due to the almost always nearby presence of eutrophicated surface water. When left alone, these soils are nearly always covered with forest. The relatively high availability of nutrients makes black alder to be the most important tree species in the low moor peat area. The dominance of birch indicates patches where this eutrophying influence is less strong. These patches occur particularly in the middle of large lots, surrounded by a zone of black alder. Only after a long period the growth of peat might form new raised bogs without trees. Controlled forestry practice is not very common in the low moor peat area. It occurs mainly in the transition zones to clay areas, like the natural levees along the streams and the transition zone to the fluvial clay area.

1.3 Contents of the report

Chapter 2 gives an overview of the methodological approach. This includes the choice of the locations, the description of stand- and site characteristics in the field and the methods used for soil sampling, solution extraction and chemical analyses. Chapter 3 gives an overview of the locations of the various forest stands on loess, clay and peat soils with a description of stand- and site characteristics.

The results of the chemical analysis of the humus layer, the mineral soil and the soil solution are presented in Chapters 4, 5 and 6, respectively. The objectives formulated in Section 1.1, are ordered in Sections of Chapters 4 and 5 for the humus layer and the mineral soil, respectively. No such subdivision is made for the soil solution. The variation in the nutrient status in the humus layer and the mineral soil, and the effects of atmospheric deposition in the nutrient status are discussed in Sections 4.1 en 5.1, respectively. The variation in the acidity status and the possible impacts of atmospheric deposition are discussed for the humus layer and the mineral soil in Sections 4.2 and 5.2 (including 5.3), respectively. The variation in the heavy metal content of the humus layer and the mineral topsoil is discussed in Sections 4.3 and 5.4.2, respectively. All these data are also made available for consecutive studies (e.g. weathering studies and scenario studies). The total contents of an additional set of elements are determined to provide a complete set of chemical characteristics of the considered soils.

Chapter 7 gives an overview of relevant issues for discussion is given, especially with respect to the methodological approach, the applicability and the imbedding of the results in complete nation-wide coverage. Finally, conclusions are given in chapter 8.

2 Methods

In this chapter we describe the selection and characterization of the locations, the sampling of the soil, the choice of chemical parameters and analyzing methods. Apart from the selection of the locations, the methods used were mostly similar to those used in the survey of the non-calcareous sandy soils (De Vries & Leeters, 1999). For more information we thus refer to De Vries & Leeters (1999) and the literature cited there.

2.1 Selection of the locations

This section gives an overview of the selection procedure. The resulting set of sampling locations from this procedure is given in Chapter 3 and Figures 1 and 2.

Criteria and procedure

The criteria used for the selection of the locations on the loess, clay and peat soils were:

- The soil of these locations had to **consist almost completely of one parent material**, i.e. loess, clay or peat, respectively. A (thin) cover of a different parent material was not allowed. The depth of the layer had to be 80 cm at least, but more than 1 m preferably. While sampling, a different parent material, starting between 80 and 100 cm sample was omitted.
- The set of locations should be **representative** for the geographical distribution in the Netherlands and diversity of each parent material, which means:
  a. for the loess soils: all types of loess soils, including loess-related soils
  b. for the clay soils: all types of (non-calcareous) clay soil, possibly both fluvial and marine
  c. for the peat soils: both low moor and high moor locations, and the whole range from very wet to excessively drained.
- The soil profile as a whole should be classified **non-calcareous** (mainly applicable for loess an clay soils). According to the System of Soil Classification for the Netherlands (De Bakker & Schelling, 1989) soils classified as non-calcareous clay soils may partly consist of carbonate-containing or carbonate-rich material.
- Only little or **no influence of seepage or surface water** was allowed, because of the buffering effect. However this effect could not be completely excluded from the wet and very wet locations on the clay and peat soils.

Principally, a first selection of the locations was based on locations of the forest inventory on vitality (SBB / IKC-NBLF, 1983-1994) combined with (the digital version of) the Soil Map of the Netherlands (Steur & Heijink, 1991; De Vries & Denneboom, 1992). Since this selection did not result in the required number of locations (40 for the loess soils and 30 for the clay and peat soils), a further selection was based on a selection of locations from other projects and data bases. Eventually the total number of locations was achieved by the selection of completely new locations. These locations were selected by making an overlay of the soil map on the forest-units on the topographic map or based on the experience of local terrain people (especially for peat soils). First a provisional set of locations was selected, based on the available data sets, filling up the requested number of locations as fully as possible. The rest of the provisional locations was selected by making an overlay of the soil map on the forest-units on the topographic map and by using the terrain knowledge of local workers. In case one or more provisionally selected locations did not fit to the criteria, these locations were either moved a little bit or replaced by completely new ones. Because the available locations from other projects were already optimally used, these extra locations were always fully new. More details about the use of the different available location sets and the newly selected locations follow below per parent material (soil type). A detailed list of all locations is given in Annex B. The resulting distribution over the Netherlands is given in Section 3.1.

Loess soils
The first selection of locations on loess soils was based on locations of the forest inventory on vitality on sheets 60, 61 and 62 of the digital Soil Map of the Netherlands. Only eleven of the 42 locations appeared to occur on loess soils. These sites are located both on *in situ* (primary) loess soils and on (secondary) colluvial and alluvial loess soils.

Two locations were selected from the data base of the survey of Van de Westeringh (1981) on *brikgronden* (luvisols) under old-growth forest. Fifteen locations were selected in two areas of the State Forest Service in Southern Limburg, of which detailed soil surveys were available: ten in the forestry area "Vaals" (Mekkink & Kleijer, 1986) and five in the forestry area "Savelsbos" (Mekkink, 1989). The more detailed scale in these surveys made it possible to select proper sites in the hill-side forests, which are mapped as a complex on the Soil Map of the Netherlands, scale 1 : 50 000.

Five supplementary locations in the Southern Limburg loess belt were selected by making an overlay of the soil map on the forest-units on the topographic map. The same method was used for the selection of seven locations in the loess areas on the sheltered sides of the ice-pushed ridges Northern Limburg and the South-Eastern Veluwe (two and five locations respectively).

Clay soils
The first selection of locations on clay soils was based on the locations of the forest inventory on vitality. This selection resulted in only one location. This location also appeared to be the only location on pleistocene ('old') fluvial clay.

A data base on forest ecosystems on clay soils (Projectgroep bosecosystemen, 1998) was the second source of locations, which finally resulted in five locations. A data base of poplar stands of the *Robusta* project (Van Delft, 1996) was the third source of locations, finally resulting in two locations.

The fourth source of locations were newly selected locations, based on the comparison of the Topographic Map 1 : 50 000 with the Soil Map 1 : 50 000. Several provisionally selected locations from the former mentioned sources were excluded because of the fragmentary ownership of the many private forests, because the trees had been cut or because for forest land was managed as coppice or holm. Exclusions were compensated by newly selected locations, which resulted in a share of 22 newly selected locations in a total of 30 locations. All 30 locations are on fluvial clay soils and none on marine clay soils, which was mainly due to the very small area of forests on non-calcareous marine clay soils.

Peat soils
The first selection of locations on peat soils was based on the locations of the forest inventory on vitality. This selection resulted in only four locations. All these locations are situated in the high moor peat area.

A data base on marsh forest ecosystems (Clerkx et al., 1994) was the second source of locations. This selection provided locations both on high moor peat and on low moor peat, twelve locations in total.

After a provisional selection, exact locations fitting the criteria were selected with the help of local experts. Especially in the first set of locations impurities and inaccuracies on the soil map caused the exclusion of many provisionally selected locations. The main reason was the shallowness of the peat cover, especially on locations which occurred within complex soil units on the soil map. Mapping of complex units was common use in these poorly accessible lands. A few locations were excluded because the trees had been cut, mainly in the framework of a campaign to re-wet peaty areas. Exclusions were compensated by a little shift of the location or by an increase of the number of newly selected locations. The 14 newly selected locations complete the total number of 30 locations on peat soils.

2.2 Characterisation of the locations

For each location an overview was made of all important characteristics of the stand itself and its surroundings. This included
- its position in the Netherlands and the spatial distribution of all locations, including -the deposition levels,
- the tree species and other stand characteristics,
- the position of the forest stand with respect to surrounding or adjacent land use,
- site characteristic.

Spatial distribution and deposition levels
Information about the position of the location and other general characteristics of the location comprised: a number and a name (mostly after the forest in which the location is situated, or after a nearby place), X and Y co-ordinates (cf. the Topographical Map of the Netherlands), the Province and the owner.

Information about the atmospheric deposition of SO_x, NO_x and NH_x for the year 1991 was derived from the National Institute of Public Health and Environmental Protection (RIVM). The deposition data were provided for each location on the basis of calculations with the model DEADM (Erisman, 1991; 1993), which include the following two facets:

- the 5 km x 5 km grid cell bulk deposition of the grid cell in which the forest is located (available at RIVM)
- the calculated site specific dry deposition, using information on the tree species, the tree height and the canopy coverage.

The total (wet and dry) deposition of (potentially) acidifying compounds and the total deposition of N containing compounds were calculated as follows:

$$Dep_{acidity} = 2 * SO_x + NO_x + NH_x \qquad (mol_c\ ha^{-1}\ a^{-1})$$
$$Dep_{nitrogen} = NO_x + NH_x \qquad (mol_c\ ha^{-1}\ a^{-1})$$

Tree species and stand characteristics
In each stand an assessment was made of the species composition of the forest canopy. In stands with more than one species the share of each contributing species was estimated. The species with the largest share in the upper canopy layer was assigned as the main tree species and as such used in the further processing of the data (e.g. the clustering of tree species).

The following other stand characteristics were determined and divided into classes:
- the canopy coverage (the projection of the canopy on the soil), i.e. < 50%, 50-75%, > 75%. For the deciduous tree species (including Japanese larch) the canopy coverage may be less reliable because of the sampling period (February-May);
- the estimated height of the stand, i.e. 0-5 m, 5-10 m, 10-15 m, 15-20 m, > 20 m;
- the coverage of the soil by short vegetation, i.e. 0%, 0-20%, 20-60%, 60-100%, 100%;
- the character of the short vegetation, i.e. grasses, indicators of eutrophication and remaining species (an indication of the present short vegetation with a score list was sometimes given but these results varied strongly, depending on the knowledge of the field worker).

Position of the forest stand
The position of the forest stand in which the location was placed, with respect to surrounding or adjacent land use, and the surrounding/adjacent land use itself were characterized by the following parameters:
- the presence of open spots or forest roads;
- the nearest distance of the trees to the edge of the forest, i.e. 0-20 m, 20-40 m, 40-60 m, 60-80 m, 80-100 m, > 100 m (measured from the centre of the sampling plot);
- the position of the nearest edge of the forest with respect to the site, i.e. north, north-east, east, south-east, south, south-west, west, north-west;
- the soil use at the nearest edge of the forest, i.e. grassland, maize, arable land and non-agricultural land such as heather or bare land.

Site characteristics
For every stand a representative description of the soil profile and water-tables class was made for the first 120-180 cm. The soil was characterized by the occurrence and thickness of A, B and C horizons and by estimated values for the organic matter content, loam (texture) and the median value of the sand grains (granular). The estimations for the clay content have been validated, using measurement of the texture classes at a selection of loess and clay samples by Van der Salm et al. (1998; and Fig. 1). The horizon nomenclature according to De Bakker & Schelling (1989) was used. This nomenclature is a slight modification of the system by the International Society of Soil Science (FAO, 1974: 20-23). The water-tables were characterized by the mean highest water-table (in the late winter) and the mean lowest water-table (in the late summer). Water-table classes were used for characteristic combinations of mean highest and mean lowest water-table (De Vries & Van Wallenburg, 1990; cf. Annex C).

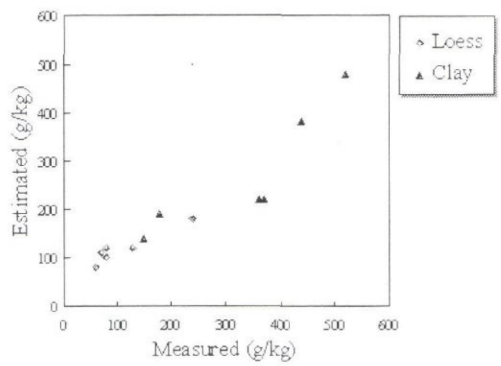

Fig. 1 Comparison of the field estimations of the clay content of a selection of loess and clay samples with laboratory measurements (source: Van der Salm, 1998).

2.3 Soil sampling and chemical analysis

2.3.1 Sampling methods

The loess soils were sampled in the period March 23 to April 13, 1992. The clay soils were sampled in the period March 8 to May 28, 1993. The peat soils were sampled in the period February 22 to April 29, 1993. These periods are within the period February through May, which is generally supposed to show the most representative concentrations for the annual flux weight solute concentration (cf. De Vries & Leeters, 1999).

Samples were taken of the humus layer and four mineral (or peat) soil layers i.e. 0-10 cm, 10-30 cm, 30-60 cm and 60-100 cm. The boundary between the humus layer and the underlying soil of the peat soils was defined by the origin of the organic material. Material which originated from litter fall (either from tree leaves or from grasses and herbs) was considered to be part of the humus layer. Original peat, peat-like materials and material which obviously originated from peat or from (*Sphagnum*) mosses was considered to be part of the soil compartment.

At each site a composite sample of each layer was taken consisting of 20 subsamples to minimize the influence of spatial variability, as with the non-calcareous sandy soils (cf. De Vries & Leeters, 1999). We chose the sample points within the forest stand according to a steady pattern. In the middle of the stand a square of 20 m x 20 m was delineated. Along the sites of this square, turning from the outside in the form of a square spiral to the inside, 20 samples were taken with a mutual distance of 5 m. In small stands a mutual distance of 3 m was used. Since laboratory capacity for drying samples of the humus layer was too small, only ten humus subsamples were taken at each location. Troedsson and Tamm (1969) showed that ten samples is generally enough to reduce the uncertainty in the mean chemical composition of the humus-layer to an acceptable value. However, 20 subsamples were taken at locations where ten subsamples would yield too little material (which in general was the case when the total thickness was less than 1 cm).

The humus layer was sampled with a cylinder of steel with a diameter of 14.8 cm. For every subsample the thickness of the litter (L)-, fermented (F)- and humus (H)-horizon (Klinka et al., 1981) plus the total thickness was notated. Where the thickness of the humus-horizon was more than 1 cm, the humus-horizon was sampled apart since literature information indicated a clear difference in the chemical composition of this layer compared to the L and F layer and because the humus-horizon gives information about the possibilities for appearance of certain plants. The L- and F-horizons were always sampled together. The green parts of the vegetation and the living roots were excluded from the sample. The mineral soil layers were sampled with stab gimlets with diameters of 3 and 1.5 cm for the top soil and sub soil, respectively. For very loose and watery peat soils thicker gimlets were necessary. By taking 20 subsamples this resulted in approximately 1 kg mineral soil, sufficient to extract solution for chemical soil solution analyses. Practically it was difficult not to disturb the mineral soil when taking a sample of the humus layer. Therefore the samples of the mineral soil were taken nearby, but not in exactly the same spot as the sample of the humus layer.

2.3.2 Parameter choice

The chemical composition of both the solid phase and the soil solution was analyzed in all mineral layers, except for soil solution of the mineral soil layer 30-60 cm of the loess soils. The samples of this one layer were not centrifugated because of a capacity reason in the laboratory.

The most important pool of nutrients in acid forest soils is the humus layer. Consequently the amounts (content) of all major nutrients, i.e. C, N, P, K, Ca, Mg and S were measured in this layer. Contents of C, N and P were also measured in the mineral layer since the C/N ratio is likely to decrease due to the high N input (eutrophication) whereas P is an important nutrient whose availability might be limited due to acidification. The pools of an additional set of nutrients and minerals (Si, Al, Ca, Mg, K, Na, Fe, Mn and Ti) were determined in all four layers of a subset of 10 loess soils and 10 clay soils and in the topsoil (0-10 cm) of all 30 peat soils. These results were used for subsequent weathering studies (Van der Salm & De Vries 1998; Van der Salm et al., 1998).

In order to gain insight in the buffer characteristics of the soil, the exchangeable cation contents (H, Al, Fe, Ca, Mg, K, Na and NH_4) and the CEC were measured both in the humus layer and the mineral topsoil. The pools of readily dissolvable Al and Fe hydroxides in the mineral layers were also measured, since it is possible that part of the forest soils are in the range of Al buffering.

The content of important heavy metals, i.e. Pb, Cd, Zn, Cu, Cr and Ni were determined for the humus layer (wherever present) and for the mineral topsoil (0-10 cm). This is done since heavy metal pollution, which is known to occur in forest soils (Kleyn et al., 1989; De Vries & Leeters, 1999), might also affect forest vitality.

In the soil solution, all the major cations and anions were determined, i.e. H, Al, Fe, Ca, Mg, K, Na, NH_4, NO_3, SO_4, Cl and $RCOO^-$.

2.3.3 Analysing methods

Total contents of C and N were determined by wet oxidation according to the methods of Kurmies (Kurmies, 1949) and Kjelldahl (Hesse, 1971), respectively. Total S contents were extracted in a concentrated mixture of nitric acid and hydrochloric acid and analysed by AAS. Total contents of P and of Ca, Mg, K, Zn, Cu, Cr and Ni in the humus layer were extracted in a concentrated mixture of sulphuric acid and nitric acid and analyzed by inductively coupled plasma atomic emission spectrometry (ICP-AES). Total contents of Pb an Cd were determined by an extraction with concentrated (9%) hydrochloric acid during three hours followed by ICP analysis of the extract. The same methods were applied for the extraction of heavy metals (Pb, Cd, Zn, Cu, Cr and Ni) in the 0-10 cm layer of all 100 locations, and of Al, Ca, Mg, K and Fe in the peat soils, also followed by ICP analysis. This methodology results a almost complete extraction for the peat soils, but may result in under-estimation for the loess and clay soils. The total contents of Si, Al, Ca, Mg, K, Na, Fe, Mn and Ti in the all four layers of 10 loess soils and 10 clays soils were extracted with fluorine, followed by ICP analysis.

Exchangeable contents of Al, Fe, Ca, Mg, K and Na were measured by extraction with a 0.01 M solution of silver thiourea (AgTu) during four hours (Chabra et al., 1975; Pleysier & Juo, 1980) followed by analyses with ICP. Exchangeable NH_4 contents were measured by extraction with 1.0 M KCl (Coleman et al., 1959) followed by analyses with a colorimetric technique (flow injection analyzer; FIA). The CEC was determined from the decrease in Ag concentration before and after the extraction (Ag is measured by ICP) and the exchangeable H content was calculated from the difference in CEC and exchangeable cation content.

Readily dissolvable contents of Al and Fe were measured by extracting the samples during four hours in the dark with an acid ammonium oxalate solution at pH 3 followed by ICP analyses of the extract (Schwertmann, 1964). In this extract the P content was also measured.

Dissolved concentrations of major ions were determined by centrifugation of a fresh soil sample of 400 gram in a POM container at 7500 rpm during 20 minutes. The soil solution samples were filtered over 0.45 μm. However the water retention in clay soils appeared to be so strong, that this method did not yield enough fluid (or even no fluid at all). Therefore 35 g of the dried clay samples were mixed thoroughly with 100 ml demi water. The suspension was centrifuged at 12,000 rpm during 2 hours. The soil solution samples were filtered over 0.10 μm, since this soil solution still contained a considerable concentration of suspended clay particles after filtering over 0.45 μm. Concentrations of P, Si, Fe, Mn, Mg, Ca, SO_4, Al, Na and K were measured by ICP. Concentrations of NH_4, NO_3, Cl and H_2PO_4 were measured by FIA. The pH was measured by means of potentiometry. H concentrations were calculated from the pH. The concentration of organic anions was calculated from the DOC content, that was measured by an organic carbon analyzer, according to Oliver et al. (1983) while assuming a weak acidity contribution of organic carbon of 5.5 $mmol_c\ g^{-1}$ C (Henriksen & Seip, 1980).

2.4 Data processing and presentation

2.4.1 Standard data processing and used software

The data have been processed with programs and special procedures within a GENSTAT 5 environment (GENSTAT 5 Committee, 1987), which have been written for the processing of soil chemical data. The data have been processed separately for the different soil compartments, i.e. humus layer, mineral soil and soil solution, separately for the loess, clay and peat soils. The data on topographic, site and stand characteristics have been processed in such a way that they could be imported in the processing of the chemical data.

For most parameters the chemical analyses provided data in a form which could be simply presented in statistics. Some of the parameters had to calculated from other, measured, parameters, using a simple formula. This the case for pools and ratios. For a few parameters it was necessary to use a pedo-transfer function, in order to calculate realistic values for parameters that can not be measured easily directly. This was the case for the organic matter content of the clay soils and for the bulk density of all soils.

A large selection of the results on the chemical composition of the humus layer, the mineral soil and the soil solution is presented in tables with the distribution per parent material (soil type). This distribution is presented by the minimum and maximum values and the 5th, 50th and 95th percentiles. Furthermore, median values (50th percentiles) are presented for the separate soil layers and for the different selected classes of one or more environmental characteristics, such as deposition level and site and stand characteristics (Section 2.2). The number of selected characteristics is limited to those which are expected to be most determining for differences within the parent materials (Table 1). The method of sub-division into layer and classes is discussed further-on. Usually the number of selected parameters for these sub-sets is smaller than for the overall data set.

Table 1 Coding of the environmental characteristics and the selection of these characteristics for the presentation of the data for the different soil compartments

Environmental characteristic	Code	Presentation of medians [1]		
		Humus layer	Mineral soil	Soil solution
Deposition of total acidity	Dp_t	-	-	X
Deposition of nitrogen [2]	Dp_n	-	-	-
Deposition of NH_x [2]	Dp_{nh}	-	-	-
Deposition of NO_x [2]	Dp_{no}	-	-	-
Deposition of SO_x [2]	Dp_{so}	-	-	-
Tree species	Tr	X	-	X
Canopy coverage	Ca	-	-	X
Tree height	He	-	-	X
Distance to forest edge [3]	Ds / Ds_w [3]	-	-	X
Direction of forest edge	Di	-	-	-
Land use at forest edge	La	-	-	X
Soil type	So	X	X	X
Drainage class [4]	Dr / Dr_c [4]	-	-	X

1) X = yes; - = no
2) Deposition of total nitrogen and the separate compounds included in the statistical analysis as alternatives for total acidity.
3) The distance to the nearest open surface water (Ds_w) was added as an alternative measure for the peat soils (Section 3.3).
4) Drainage classes were also treated as values on a continuous (non-)linear scale (Dr_c) in the statistical analysis, which gave different results if the number of classes was three or larger (i.e. for the clay and peat soils).

2.4.2 Re-calculations with pedo-transfer functions

The measured organic matter contents of the clay soils have been corrected for the loss of crystal water and carbonates during the 'loss on ignition', which depend on the clay contents. The estimations for the clay content are the main variable in the correction of the organic matter contents (Table 2): the larger the clay contents the larger the downwards correction of the organic matter contents.

For most soil types the bulk density is correlated with the texture and the organic matter contents. For many types of sandy soils, loess soils, clay soils and peat soils formulas have been derived, which contain one or more of the following elements: de clay content, the organic matter contents and the horizon code. Table 2 gives an overview of the formulas used for the calculation of the bulk density.

Table 2 Pedo-transfer functions used for the correction of the measured organic matter contents in clay soils and for the estimation of the bulk density

Soil type	Formula	Application	Reference
Correction of organic matter contents			
Loess soils	$OrgMat\%_{calculated} = OrgMat\%_{measured} - (0.41 + 0.064 * Clay\%)$		
Clay soils	*idem*		
Calculation of bulk density			
Loess soils *(standard)*	$\rho = 1425$	for A horizons	Hoekstra & Poelman, 1982
	$\rho = 1560$	for B horizons	Hoekstra & Poelman, 1982
	$\rho = 1535$	for C horizons	Hoekstra & Poelman, 1982
clayey [1] *fraction*	formulas for clay soils (see below)		
sandy [1] *fraction*	$\rho = \frac{1000}{0.646 + 0.025 * OrgMat\%}$	for A horizons	Hoekstra & Poelman, 1982
	$\rho = 1449$	for E horizons	Hoekstra & Poelman, 1982
	$\rho = \frac{1000}{0.651 + 0.021 * OrgMat\%}$	for B horizons	Hoekstra & Poelman, 1982
	$\rho = \frac{1000}{0.602 + 0.039 * OrgMat\%}$	for C horizons	Hoekstra & Poelman, 1982
Clay soils	$\rho = \frac{1000}{0.618 + 0.023 * OrgMat\% + 0.00067 * Clay\%}$	for A/E horizons	Hoekstra & Poelman, 1982
	$\rho = \frac{1000}{0.572 + 0.0053 * OrgMat\% + 0.0039 * Clay\%}$	for B/C horizons	Hoekstra & Poelman, 1982
Peat soils	$\rho = 826 - 337 * \log(OrgMat\%)$	OrgMat% > 30%	Van Wallenburg, 1990

[1] For definitions and weighing procedure see text.

For the peat soils only one formula was used, whereas for the loess and clay soils different formulas per horizon were used. If one sample comprised two different horizons, thickness-weighed average of the two applicable bulk densities has been calculated. The calculated bulk densities for the loess soils haven been corrected if the soils were more sandy or more clayey that the regular loess soil. A loess soil was considered to be regular if the clay and sand contents were below 15%. If the sand or clay content were beyond these limits, a 'mixing factor' or 'weighing factor' was calculated. For the clayey fraction a linear relation was assumed between 15 and 30% of clay. Above 30% the soil was considered to be a pure clay soil. For the sandy fraction a linear relation was assumed between 15 and 90%. Above 90% of sand the soil was considered to be a pure sandy soil. The formulas for clay soils and sandy soils were applied for the clayey fraction and the sandy fraction, respectively. The bulk density was calculated as the percentage-weighed average of the values for the fractions.

2.4.3 Calculation of critical heavy metal content levels

The contents of heavy metals have been analysed in the humus layer, where-ever present (i.e. for most locations on loess and peat soils) and in the topsoil (0-10 cm) of all locations. In order to classify the observed contents into pollution classes, the regular Dutch evaluation system has been applied.

In the Netherlands a system of critical levels is used for the evaluation of the contents of pollutants in soil and ground water. For the heavy metal contents of the soil these levels depend on the lutum (clay; L) and humus (organic matter; H) content of the soil. This relation is based on the assumed background values of the polluting substances in relation with the mineral characteristics of the soil material and the origin and history of the soils.

The Dutch systems recognizes three critical levels for each pollutant:
- the **Target Value** (Dutch: *Streefwaarde*, S), i.e. the assumed maximum for the range of background values,
- the **Intervention Value** (Dutch: *Interventiewaarde*, I), i.e. the minimum value for serious pollution, indicating that any action to clean, remove or isolate the polluted part of the soil is necessary,
- the **Examination Value** (Dutch: *Toetsingswaarde*, T), i.e. the value above which more research to the extent and the source of the pollution is necessary, calculated as the mean value of Target and Intervention Value.

For each pollutant the same formula can be used for the calculation of the Target and Intervention Value. This formula consists of the values for the separate pollutants in a standard or reference soil (L=25%, H=10%) and a formula to correct for non-standard soils. If the organic matter content is lower that 2%, the calculation is done with an organic matter content of 2%. The formulas for the Target Value (S) and Intervention Values (I) follow here:

$$S = S_{st} * \frac{A + B*L + C*H}{A + B*25 + C*10}$$

$$I = I_{st} * \frac{A + B*L + C*H}{A + B*25 + C*10}$$

These formulas apply for all considered heavy metals. The height of the critical values for the reference soil and the coefficients in the formulas, however, are different for the various heavy metals (Table 3).

Table 3 Critical heavy metal contents for the reference soil (L=25%, H=10%) and adjustment coefficients for non-standard soils

Element	Reference soil		Coefficients		
	S_{st} (ppm)	I_{st} (ppm)	A	B	C
Lead (Pb)	85	530	50	1	1
Cadmium (Cd)	0.8	12	0.4	0.007	0.021
Copper (Cu)	36	190	15	0.6	0.6
Zinc (Zn)	140	720	50	3	1.5
Nickel (Ni)	35	210	10	1	0
Chromium (Cr)	100	380	50	2	0

2.4.4 Statistical design and statistical analysis

From a statistical point of view, the design of this project is based on two strata: the location stratum and the layer stratum. This means, that the total variation in the results for the solid phase (i.e. 'mineral soil') and the fluid phase (i.e. 'soil solution') can be accounted to two different sources of variation: the within-location variation (i.e. between the layers of each location) and the in-between-location variation. These two sources of variation are separated as much as possible in the analysis and presentation of the results. The overall overview of the results per variable (minimum ... maximum), however, is presented for all results for this variable, except for the pools, that have always been lumped per location. The influence of the depth (i.e. the differences between the sampled soil layers) is presented by tables with the median value per layer of each variable. The significance of the environmental characteristics is given by the addition of the explained variance by each presented characteristic. For the deposition variables the actual levels have been used in the regression analysis, instead of the classes.

Furthermore, statistical analyses are conducted to determine which characteristics determine most the distribution of the response parameter. This was done by multiple linear regression techniques with step-wise selection. A hierarchic ordering was built in the multiple regression analysis, in order to include probable characteristics first and to avoid artefacts. This was accomplished by a different order of adding possible predictors to the model, depending on the soil compartment (humus layer, mineral soil and soil solution). For each compartment a very small selection of the most probable predictors was used as a starting point. Then, in three stages the model was extended with all the available predictors. In each stage the criteria for addition of a characteristic were tightened. The results for the regression analysis are expressed by the percentage of explained variance (% R^2_{adj}) by the regarded model, as well as by the significance of this fit. This significance is divided into four classes of significance: not significant ($P \geq 0.1$), slightly significant ($P < 0.1$), significant ($P < 0.01$), strongly significant ($P < 0.001$).

Besides the single characteristics, a very limited number of interactions was included in the model, namely the interaction between the various deposition variables with the soil type and with the drainage class. Interactions between the deposition variables and other stand characteristics were not included, since (i) these characteristics were also used in the derivation of deposition estimates and (ii) this would lead to an excessive consumption of degrees of freedom compared with a limited number of available data. This latter argument also applies for the omission of other possibly relevant interactions, e.g. between soil type and drainage class.

As a starting point a model was built with the most likely predictor variables: soil type and tree species for the humus layer, soil type and drainage class for the mineral layers and soil type, drainage class and tree species for the soil solution (Table 4; step 0). In the first stage of step-wise regression the significance of these predictor variables was tested, resulting in a new base model. In the second stage the remaining site and stand characteristics were added and in the third stage also the interactions between the deposition variables with soil type and drainage class. The result of this analysis is presented in tables which contain (i) the statistical model after the first and the third modification step, (ii) the percentage of explained variance (% R^2_{adj}) by this model and (iii) the significance of the correlation.

Table 4 Predictor variables included in the successive stages of step-wise regression

Compartment	Step	Available predictor variables included/added [1]
Humus layer	0	So + Tr
	1	(same)
	2	+ Dr/Dr_c + (Dp_t + Dp_n + Dp_{nh} + Dp_{so}) + Ca + He + Ds + Ds_w[2] + Di + La
	3	+ So.(Dp_t,Dp_n,Dp_{nh},Dp_{so}) + Dr.(Dp_t,Dp_n,Dp_{nh},Dp_{so})
Mineral soil	0	So
	1	+ Dr/Dr_c
	2	+ Tr + (Dp_t + Dp_n + Dp_{nh} + Dp_{so}) + Ca + He + Ds + Ds_w[2] + Di + La
	3	+ So.(Dp_t,Dp_n,Dp_{nh},Dp_{so}) + Dr.(Dp_t,Dp_n,Dp_{nh},Dp_{so})
Soil solution	0	So + Dr/Dr_c + Tr
	1	(same)
	2	+ (Dp_t + Dp_n + Dp_{nh} + Dp_{so}) + Ca + He + Ds + Di + Ds_w[2] + La
	3	+ So.(Dp_t,Dp_n,Dp_{nh},Dp_{so}) + Dr.(Dp_t,Dp_n,Dp_{nh},Dp_{so})

1) Coding cf. Table 1

2) Distance to open water/reed land only for peat soil

In the interpretations of the regression analysis, it should be considered that the various deposition variables maybe strongly correlated. This counts for the correlation between the separate compounds, but even stronger for the sum variables (total N and total acidity). Therefore, these variables are often more or less exchangeable. If one if the factors is selected in the statistical procedures, it can often be exchanged with the other factor, with only little loss of explained variance. Preliminary statistical analysis showed that the deposition variables often appear in combinations in a selected 'best model', if all deposition variables were set available for selection. The problem was that a second deposition was always included with an opposite sign compared to the first one. A third deposition variable again appeared with the same sign as the first one (so opposite to the second one). This problem is probably related to the extend of correlation between these variables.

In order to counter mixing up of the various deposition variables, each statistical selection procedure was carried out with only one deposition variable and its interaction terms (i.e. steps 2 and 3 were done 5 five times for each analysed variable, one time for each deposition variable). In the results only the best explaining model from these five has been showed.

Most environmental characteristics have been assessed in classes. For some of these variables, however, this classification was based on qualitative class limits on a continuous scale. An attempt to quantify the contents of a certain class was done, if such cases, especially if a continuous (linear or non-linear) relationship was expected between these characteristics and the soil chemical response variables. Side effect of this conversion was that the number of degrees of freedom was reduced, required by the inclusion of this variable in the explanatory model. The class middles (approximately) were used for the following characteristics: tree height, canopy closure and distance to the nearest forest edge. The (eight) classes in the direction towards the nearest forest edge have been treated as points on a ring with radius 1 encircling the plot.

The distance to open water and/or reed land has been added as explanatory variable for the peat soils. This measure has been set equal to the distance to the forest edge, if the bordering land use type was open water or reed land, and set to the value of the class '>100m', if the location bordered to a different land use type. It was considered that the proximity of open water or reed land could affect the chemical soil conditions by the mixing up of ground water and surface water with certain chemical characteristics.

The drainage class was also assessed in classes. The ordinal character of these classes was principally not included in the analysis of the drainage class as a nominal predictor. Therefore, the class number of the drainage class has been defined as an alternative explanatory variable. This variable gives different outputs for analysis with three or more classes, assuming a (non-)linear relationship between the class number and the response variables.

The testing of the significance of the differences between the layers was conducted on the differences between the observed values for the various layers with the plot-mean values. The values for the explained variance were added to the tables with median values per layer. Furthermore, an analysis was carried out of the environmental characteristics that determined the differences between the layers. These results are, however, not included in this report. Moreover, the statistical analysis that were carried out for the plot-mean values (see above) were also carried out for the separate layers. The results of these analyses are included in Annex E.

3 Characterisation of the forest stands

3.1 Spatial distribution and deposition levels

Figures 1 and 2 show maps of the Netherlands with the distribution of the hundred selected locations (40 locations on loess soils, 30 locations on non-calcareous clay soils and 30 locations on peat soils), compared with the distribution of these soils and with the forest area, respectively. A detailed list of the locations is given in Annex B.

The locations on loess soils are concentrated in the southern part of the province of Limburg (33 locations). Furthermore two locations are located in the loess area near Nijmegen and five in the loess area of the South-eastern Veluwe, which are quite remote from those in the Southern Limburg loess area. All 33 locations in Southern Limburg and one of the locations near Nijmegen are in the Province of Limburg. The other location near Nijmegen and the five locations on the South-eastern Veluwe are in the Province of Gelderland.

The locations on non-calcareous clay soils are concentrated in a belt in the centre of the Netherlands, which reflects the floodplain of the rivers Rhine and Meuse which forms a 20-40 km wide east-west belt from the German border towards the west, where a transition occurs from the fluvial clay area to the low moor peat area and the tidal-estuarine (marine) clay area. A few locations are to be found further upstream (south) along the Meuse and its contributary Roer. Another few locations are located in the River IJssel valley and the Oude IJssel area (further north-east). Within the large floodplain the locations are usually located in the (non-calcareous) backswamp areas farther away from the rivers. Most locations (19) are in the Province of Gelderland. The other locations are in the Provinces of Utrecht (seven), Limburg (three) and South-Holland (one) (Fig 2).

The locations on peat soils are mainly concentrated in a few areas where peat soils occur with a forest cover. The low moor peat sites appear roughly in the north-western part of the Netherlands (ten locations), whereas the high moor peat sites roughly appear in the south-eastern part of the country (20 locations). Most locations appear in clusters, because the locations had to be selected in a limited number of areas with peat soils that fitted the posed criteria. The locations are distributed over eight of the twelve Provinces of the Netherlands: North-Holland (three), Utrecht (two), South-Holland (two), North-Brabant (five), Limburg (two), Drenthe (seven), Gelderland (three) and Overijssel (six).

For all three parent materials, a large variation was estimated for the total deposition of acidity (Table 5) and for the deposition of the various depositing compounds (Table 6). This variation offers good possibilities for the assessment of relationships between the various soil chemical variables and atmospheric deposition variables.

The highest deposition of total acidity was estimated for the clay soils (Table 5). The estimated deposition for the loess soils was slightly higher than for the peat soils. The same pattern was found for the individual compounds (Table 6). The deposition of the various compounds is generally well to strongly correlated with the total deposition figures, except for the NO_x and SO_x deposition for the peat soils.

Table 5 Distribution of the forest stands over the deposition level classes of potential acidity

Total deposition ($mol_c\ ha^{-1}\ a^{-1}$)	Numbers per deposition class			Numbers per N deposition class			N deposition ($kg\ ha^{-1}\ a^{-1}$)
	Loess [1)]	Clay	Peat	Loess [1)]	Clay	Peat	
< 3000	0	0	0	0	0	0	< 20
3000 - 4000	1	0	2	0	0	7	20 - 30
4000 - 5000	7	1	11	21	1	10	30 - 40
5000 - 6000	23	1	10	17	5	8	40 - 50
6000 - 7000	9	10	4	2	21	2	50 - 60
7000 - 8000	0	16	2	0	3	2	60 - 70
> 8000	0	2	1	0	0	1	> 70

[1)] One meadow and one recently cut poplar stand are not taken into account.

Table 6 Distribution of the forest stands over the deposition level classes of the individual components and correlation with total deposition

Deposition ($mol_c\ ha^{-1}\ a^{-1}$)	Loess [1)]				Clay				Peat			
	NH_x	NO_x	N_{tot}	SO_x	NH_x	NO_x	N_{tot}	SO_x	NH_x	NO_x	N_{tot}	SO_x
< 1000	0	30	0	1	0	2	0	0	0	20	0	0
1000 - 2000	2	10	0	10	0	28	0	2	10	10	0	20
2000 - 3000	36	0	6	28	13	0	1	19	15	0	10	10
3000 - 4000	2	0	32	1	17	0	3	9	0	0	15	0
4000 - 5000	0	0	2	0	0	0	23	0	4	0	2	0
> 5000	0	0	0	0	0	0	3	0	1	0	3	0
Corr. with Total deposition (%)	*82*	*75*	*90*	*80*	*70*	*90*	*84*	*85*	*89*	*36*	*94*	*27*

[1)] One meadow and one recently cut poplar stand not taken into account.

3.2 Tree species and stand characteristics

Many locations on loess soils consist of more than one tree species. The variable composition complicates the clustering of the stands per tree species. The stands have thus been sorted on the basis of the dominant tree species. This method implies that in many stands tree species occur which also occur in other clusters, either as the main tree species or as one of the 'minor' species. One stand appeared to be cut very recently and one of the locations appeared to be a meadow. For unclear reasons, these two locations have not been excluded from the set of locations before sampling. These locations have been treated like the 'normal' locations as far as possible, except

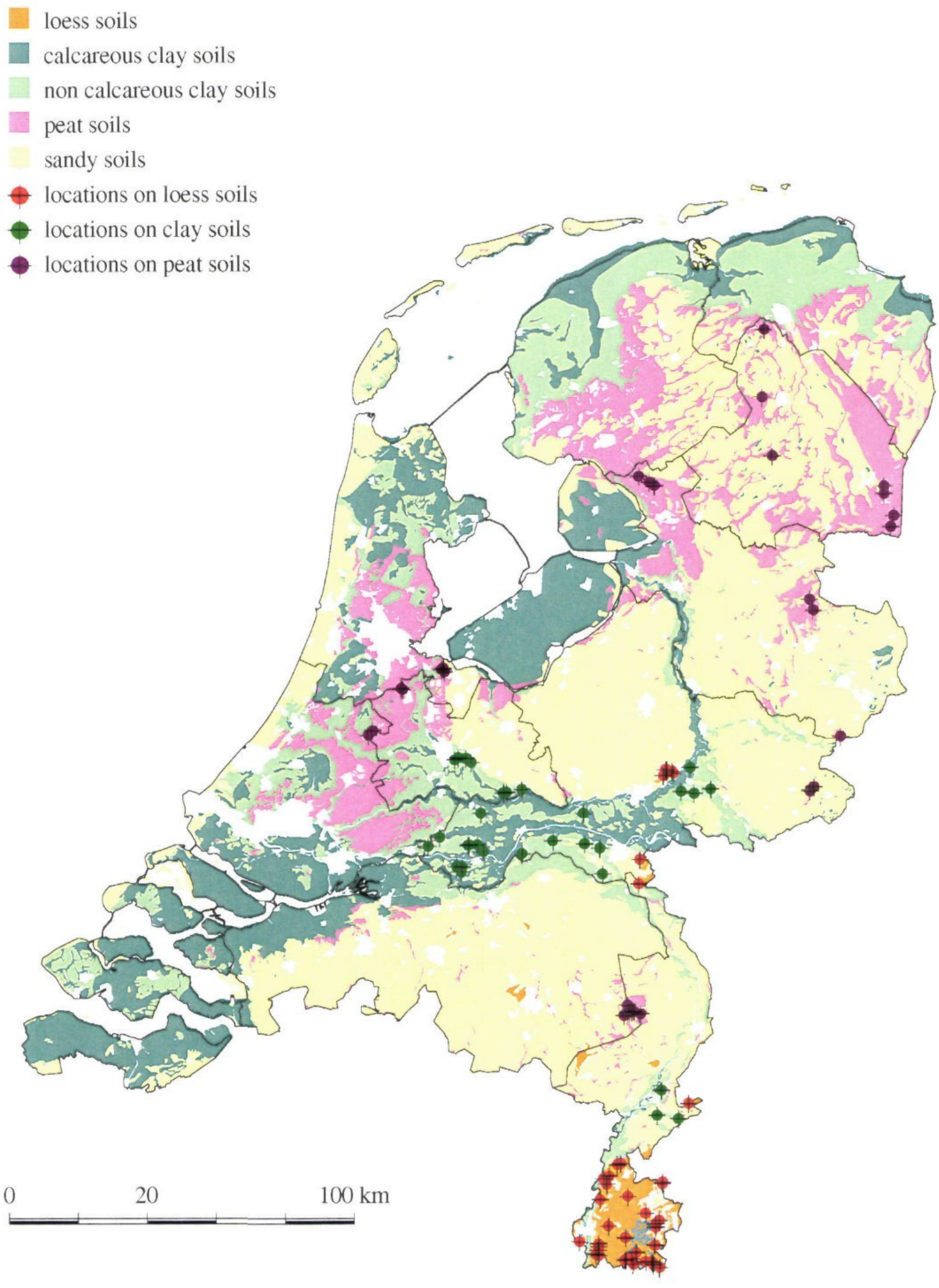

Fig. 2 Spatial distribution of the 100 locations in comparison with the distribution of the loess, clay and peat soils

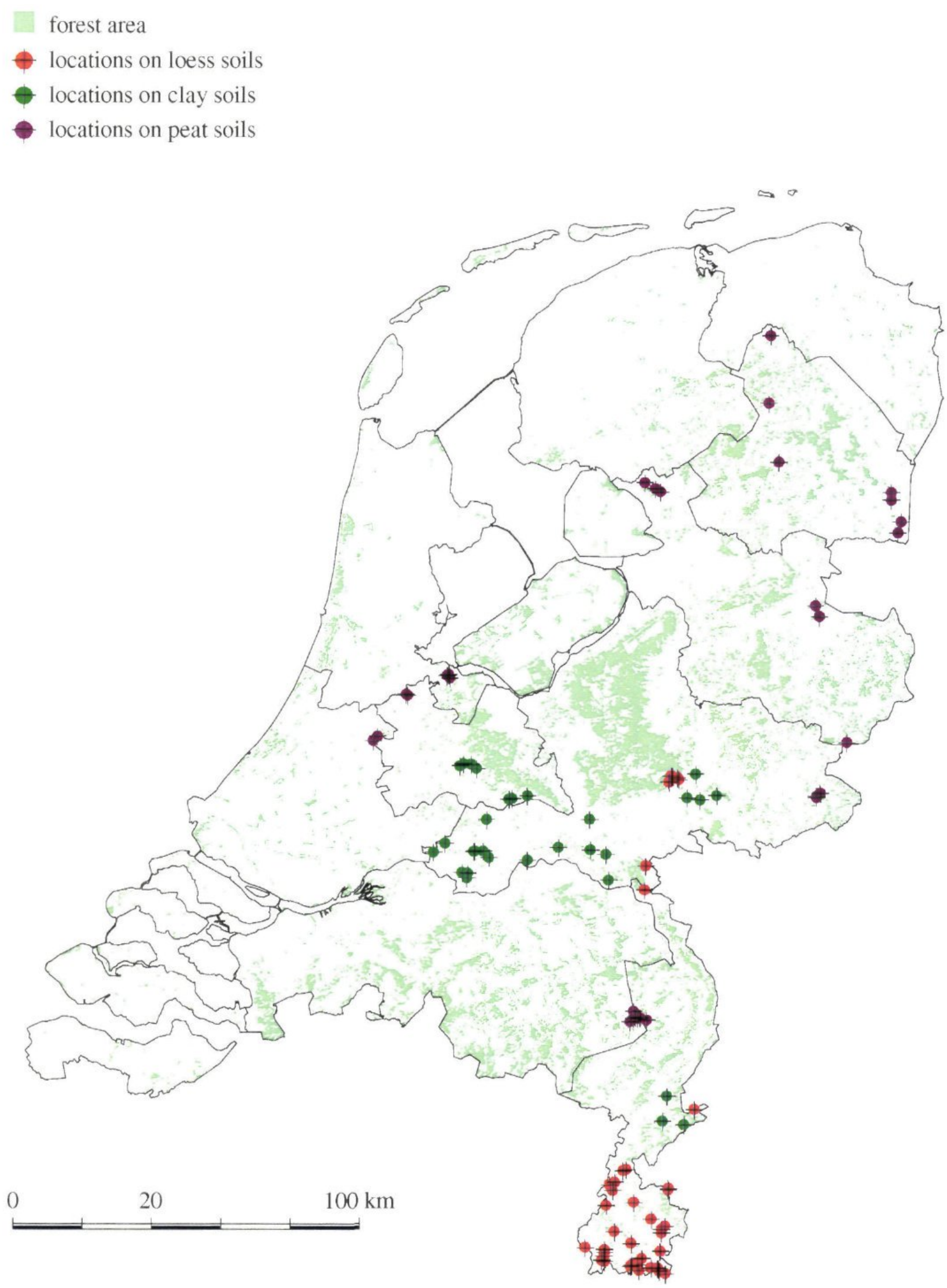

Fig. 3 Spatial distribution of the 100 locations in comparison with the distribution of the forest area

for the presentation of the stand characteristics. The meadow location has also been excluded from the characterization of the position of the forest stand. In the set of 40 stands, 12 different tree species were found to be the main species, one 'stand' being a meadow. The stands have been clustered in four groups, according to the extent of coexistence of the species and to similarity in properties of the canopy:

- 'Oak' (20 locations), containing the following main tree species: Pedunculate Oak (*Quercus robur*), Red Oak (*Q. rubra*) and Birch (*Betula* spp.);
- 'Beech' (seven locations), containing the following main tree species: Beech (*Fagus sylvatica*) and Sweet Chestnut (*Castanea sativa*);
- Other deciduous species ('O. dec.', nine locations), containing the following main tree species: Hybrid Poplar (*Populus* x *euramericana*), Black Alder (*Alnus nigra*), Maple (*Acer pseudoplatanus*) and Black Cherry (*Prunus avium*); and
- Conifers ('Conif.'; four locations): containing the meadow and the following main tree species: Norway Spruce (*Picea abies*), Scots Pine (*Pinus sylvestris*) and Japanese Larch (*Larix kaempferi*).

The most common tree species in the stands on clay soils is Poplar (*Populus* x *euramericana*), which is dominant in 17 of the 30 selected stands. All these stands are poplar plantations. In about half of the poplar plantations a second tree layer is present, consisting of one or more other tree species. The presence of such an understorey was used as a key for the separation of this large group into two smaller groups. The stands without a understorey are usually young plantations with a ground vegetation dominated by stinging nettle (*Urtica dioica*). For the stands with a second storey, this characteristic was considered as an indicator of more stable (more mature) ecological conditions. The ground vegetation of these stands is generally better developed and consists of many more species. One stand of Gray Poplar (*Populus* x *canescens*) has been included in this group. Besides poplar, four other main species were found, that have been clustered in one group for further examination, making the following three groups:

- 'Poplar pure' (nine locations): the young monotonous poplar plantations;
- 'Poplar mix' (nine locations): the better structured, more mature poplar stands;
- Other deciduous species ('O. dec.', twelve locations), containing the following main tree species: Indigenous Oak (*Quercus robur*), Ash (*Fraxinus excelsior*), Beech (*Fagus sylvatica*) and Elm (*Ulmus minor*).

The common tree species of the stands on peat soils is Birch (*Betula spp.*), which is the dominant species in 26 of the 30 selected stands. In two stands Black Alder (*Alnus glutinosa*) is the dominant species with birch being the second tree in dominance. Two stands are plantations of Oak (*Quercus robur*). This uneven distribution was not suitable for a separation in species-oriented groups. Therefore, the secondary species in the birch stands were used as a criterium for subdivision. A first group that was distinguished were the stands that contained at least a few alders. These stands were considered to form the transition towards the alder carr ecosystems, which are more likely to be affected by seepage water and which might also be affected by the N assimilation by in the roots of the alder trees. A second group are the stands with other deciduous species besides birch, but without alder. These species include oak, pine and *Sorbus aucuparia*. These stands are considered to form the transition to oak-birch ecosystems (*Betulo-Quercetum*), which are more likely to occur on poor sandy soils. The remaining stands contain only birch in the tree and shrub layers. This dub-division resulted in the following distribution:

- 'Birch' (twelve locations), the stands with birch only;
- 'Birch / oak' (twelve locations), the stands with oak, pine, *Sorbus aucuparia* etc. as a secondary species, including the two stands dominated by oak;
- 'Birch / alder' (six locations), the stands with alder as a secondary species, including the two stands dominated by alder.

A comparison of the distribution of tree species found here with the overall distribution of the species in the Netherlands or in the various Provinces (as done for the forests on sandy soils by De Vries & Leeters, 1999) is not useful, since the areas of forest on loess, clay and peat soils are very small in comparison with the total forest area of the Netherlands. For example, even in the Province of Limburg, where more than 90% of the loess soils of the Netherlands occur, these forests do not have a significant share in the total forest area of the Province. Most of the forest in this Province is situated on the sandy soils in the north-western part.

Most stands have a canopy coverage of more than 75%: just over half of the locations on loess soils and about three quarters of the stands on clay soils and peat soils (Table 7). The big share of locations on loess soils with a canopy coverage of less than 75% is mainly due to the tree species 'oak' and 'coniferous'. Field observations proved that the lower canopy coverage in these stands could been attributed to either recent thinnings or to poor tree condition or to both. The stands on clay soils with a canopy coverage of less than 75% are mainly very open or strongly thinned poplar plantations. On the contrary, a canopy coverage of less than 75% for the stands on peat soils always coincided with a poor forest vitality, since only two or three stands were managed regularly (and those stand had a high canopy coverage). However, also the occurrence of the forests on peat soils close to the natural tree limit caused by wetness may be one of the reasons for the low canopy coverage in a few stands on peat soils.

Table 7 Distribution of the forest stands (per tree species) over the canopy classes

Canopy coverage (%)	Loess				Clay			Peat		
	Oak	Beech	Other dec.[1]	Conifers[2]	Poplar (pure)	Poplar (mix)	Other decid.	Birch	Birch +oak	Birch +alder
< 50	0	1	0	1	3	0	1	0	0	0
50 - 75	12	1	1	2	2	1	0	4	3	2
> 75	8	5	7	0	4	8	11	8	9	4

[1] One recently cut poplar stand is not taken into account.
[2] One meadow is not taken into account.

Most of the stands are higher than 20 m (Table 8). The stands which are lower than 20 m are usually young stands in which the trees still have the possibility to grow. To the contrary, the selected forest stands on peat soils are lower than 15 m and 40% is even lower than 10 m. Most of the trees observed at the peat locations did not show very much current length increment. The nutrient status, the wet conditions and the weak soil do obviously not permit the trees to grow taller than 15 m.

Table 8 Distribution of the forest stands (per the tree species) over the tree height classes

Tree height (m)	Loess				Clay			Peat		
	Oak	Beech	Other dec.[1]	Conifers[2]	Poplar (pure)	Poplar (mix)	Other decid.	Birch	Birch +oak	Birch +alder
< 5	0	0	0	0	0	0	0	0	0	0
5 - 10	0	0	0	0	0	0	1	7	2	3
10 - 15	2	0	1	0	0	0	2	5	10	3
15 - 20	9	2	5	0	0	3	3	0	0	0
> 20	9	5	2	3	9	6	6	0	0	0

[1] One recently cut poplar stand is not taken into account.
[2] One meadow is not taken into account.

3.3 Position of the forest stands

Many locations on loess, clay and peat soils occur relatively close to a forest edge (Table 9). Only one quarter of the locations on loess soils, 10% of the locations on clay soils and 20% of the locations on peat soils occur in forests with a distance to the nearest edge above 100 meters. Most locations on loess soils occur in the hill-side forests which form relatively narrow strips along the slopes in Southern Limburg. Ten locations on peat soils are located even less than 20 m from the nearest forest edge. Many locations on peat soils occur on little ridges or small parcels in the cut-over peat areas, that are just high enough above the water-table to allow tree growth. The high share of locations on clay soils in the 20-40 meter class (more than 50% !) reflects the size of the parcels on which these stands have been planted. Many stands are not larger than one or two regular agricultural parcels.

Table 9 Distribution of the forest stands (per tree species) over the distance classes to the nearest forest edge

Distance to edge (m)	Loess				Clay			Peat		
	Oak	Beech	Other decid.	Conifers[1]	Poplar (pure)	Poplar (mix)	Other decid.	Birch	Birch +oak	Birch +alder
< 20	4	1	0	0	0	1	0	6	2	2
20 - 40	1	2	5	1	6	3	10	1	4	2
40 - 60	1	1	4	0	2	2	0	2	1	0
60 - 80	5	1	0	0	1	0	0	0	2	1
80 - 100	3	0	0	0	0	1	1	0	1	0
> 100	6	2	0	2	0	2	1	3	2	1

[1] One meadow is not taken into account.

The most common surrounding land use type of the locations on loess and clay soils is grass land (Table 10).The grass lands bordering the locations on loess soils are mostly located in the river valleys and on the lower terraces, between the hill-side forests and the forest stands in the river valleys. The arable land and maize fields are mainly situated on the plateaus, at the upper edge of the hill-side forests. The forest locations on clay soils are mainly situated on heavy clay soils in the backswamp areas of the river plains. These lands have poor drainage conditions and tillage is hardly possible. Therefore they are mainly used as grass lands in agriculture. The few locations bordering to arable land are on better drained soils with a lighter texture.

More than half of the locations on peat soils do not border agricultural land. They are mostly part of nature reserves with a complex pattern of forests, bushes, reed lands, heath or heath-like lands and open waters. Most of the other locations on peat soils are bordered by grass land, which can be explained by the very wet conditions of both the selected stands and the surrounding lands. Grass land is the only possible agriculture under these conditions. The class 'other' contains only reed lands, open water and heath-like lands (former bogs). The numbers for reed lands and open water have been added to the results of Table 10 as a separate class. The remaining eight locations border to heath-like lands.

Table 10 Distribution of the forest stands (per tree species) over the surrounding/adjacent land use types

Land use type	Loess				Clay			Peat		
	Oak	Beech	Other decid.	Coni-fers[1]	Poplar (pure)	Poplar (mix)	Other decid.	Birch	Birch +oak	Birch +alder
Maize field	1	1	1	0	0	0	0	0	1	0
Grass land	13	5	4	0	9	6	10	4	3	3
Arable land	1	0	2	2	0	1	2	0	2	0
Other (water,reed)	5	1	2	1	0	2	0	8 (4)	6 (2)	3 (3)

[1] One meadow is not taken into account.

At first sight, the distribution of the locations over the classes in the direction towards the forest edge seems full of uneven distributions (Table 11). This is, however, mainly due to the small number of locations (per tree species cluster) compared to the relatively large number of classes. The distribution over the directions to the closest forest edge considerably more equally divided over the eight mentioned directions, when all locations per parent material are considered all together, with only a few over-representations and a few under-representations.

Table 11 Distribution of the forest stands (per tree species) over the directions of the nearest edge

Direction of forest edge	Loess				Clay			Peat		
	Oak	Beech	Other decid.	Coni-fers[1]	Poplar (pure)	Poplar (mix)	Other decid.	Birch	Birch +oak	Birch +alder
North	3	0	2	0	1	1	0	4	1	1
North-east	1	2	1	0	1	1	0	0	1	1
East	5	2	1	1	1	3	1	0	2	3
South-east	1	0	2	0	0	0	2	1	0	0
South	2	0	1	0	1	3	3	3	1	0
South-west	3	1	0	0	0	0	2	2	3	0
West	3	2	1	1	4	0	2	2	2	0
North-west	2	1	1	1	2	1	2	0	2	1

[1] One meadow is not taken into account.

3.4 Site characteristics

Site characteristics include the soil type and water-table class, which influence the processes occurring in the soil such as weathering and nitrogen transformations.

3.4.1 Soil types

3.4.1.1 Classification, clustering and distribution over the tree species

According to the classification system for the soils of the Netherlands by De Bakker & Schelling (1989), a large number of different soil types have been distinguished, 23 for loess soils, nine for clay soils and nine for peat soils (ten, if the difference between high moor and low moor is added). Most of these types occur only once or just a few times. These soils were clustered into larger groups: four groups for loess soils, three groups for clay soils and three groups for peat soils. The clustering was done on the basis of differences in their expected vulnerability for acidification. Table 12 gives an overview of distinguished soil groups, named according to three different soil classification systems: the FAO system (FAO, 1988), the USDA system (USDA, 1975) and the Dutch system (De Bakker & Schelling, 1989). They are listed in decreasing order of expected vulnerability for acidification (and eutrophication).

Table 12 Overview of the distinguished soil groups named according to three different classifications[1)]

FAO (1988)	USDA (1975)	De Bakker & Schelling (1989)
Loess soils:		
Eutric Cambisols (sandy loess)	Udorthents (sandy loess)	Ooivaaggronden (sandy loess)
Eutric Cambisols (loamy loess)	Udorthents (loamy loess)	Ooivaaggronden (loamy loess)
Haplic / Gleyic Luvisols	Hapludalfs / Ochraqualfs	Brikgronden
Eutric / Calcaric Fluvisols	Udifluvents	Ooivaag/Poldervaaggronden (fluvial)
Clay soils:		
Eutric Fluvisols (medium-textured)	Fluvaquents (medium-tex.)	Poldervaaggronden (medium-tex.)
Eutric Fluvisols (fine-textured)	Fluvaquents (fine-textured)	Poldervaaggronden (fine-textured)
Calcaric Fluvisols	Fluvaquents (calcareous)	Poldervaaggronden (calcareous)
Peat soils:		
Fibric Histosols (high moor)	Sphagnofibrists (high moor)	Vlier/Vlietveengronden (high moor)
Terric Histosols (high moor)	Medihemists (high moor)	Made/Koopveengronden (high moor)
Fibric Histosols (low moor)	Sphagnofibrists (low moor)	Vlier/Vlietveengronden (low moor)

[1)] Numbers in Tables 13, 15 and 17.

The relations between tree species and soil type are connected with the demands of the tree species, which is reflected in the distribution of the different tree species over the soil types. This is illustrated in Tables 13, 15 and 17 for the soil types in loess, clay and peat, respectively. However, many of the stands are mixed, especially on the loess soils, and most of the tree species also occur in stands with a different main tree species.

3.4.1.2 Soil types in loess

Almost half of the 40 stands on loess soils in this research were found on Eutric Cambisols in loamy loess. About a quarter (eleven) were found on Luvisols. Stands on Eutric Cambisols in sandy loess and on Fluvisols even have a smaller share, about a seventh (six) and a tenth (four) respectively (Table 12). The soils differ clearly in their clay contents, that varies between ca 8% for the Eutric Cambisols in sandy loess to ca 16% for the Fluvisol. More information follows below.

The soil types are not evenly distributed over the tree species. The stands of Oak and of Conifers do not occur on the Fluvisols (Table 13). These species have relatively little demands for nutrients and moisture. The 'other' deciduous tree species have, in general, greater needs. Consequently these species do not occur on the relatively poor Eutric Cambisols in sandy loess, and occur relatively often on the Fluvisols. Beech has an intermediate position, which reflects the overall distribution over the soil types.

Table 13 Distribution of the forest stands (per tree species) over the soil types in loess soils

Soil type	Oak	Beech	Other dec.	Conifers	Total
Eutric Cambisol - sandy loess [1)]	5	1	0	1	6
Eutric Cambisol - loamy loess	10	3	3	2	19
Haplic and Gleyic Luvisol	5	2	3	1	11
Eutric and Calcaric Fluvisol	0	1	3	0	4

[1)] Including Carbic Podzols (Heerlen type of Veldpodzol; one location).

Eutric Cambisols (FAO, 1988) or Udorthents (USDA, 1975) *in sandy loess* were found in six of the 40 stands on loess soils. This group contains the Dutch 'Ooivaag' soils in sandy loess. This group differs from Eutric Cambisols in loamy loess by the lower content of silt (50-85%) and the higher content of (coarse) sand. One stand with a Carbic Podzol (Dutch: the Heerlen type of 'Veldpodzol') in Tertiary sand is included in this group. At only one location gravel occurred in the subsoil, starting between 40 and 120 cm. The average organic matter content in the topsoil (0-10 cm) was 3.7%. The average thickness of the humus layer was 5.7 cm.

Eutric Cambisols (FAO, 1988) or Udorthents (USDA, 1975) *in loamy loess* were found in 19 of the 40 stands on loess soils. This group contains the Dutch 'Ooivaag' soils in loamy loess. The soils in this group have a high content of silt (over 85% in the < 50 μm fraction). Unlike the Luvisols, the soils of this group do not have an Argillic B horizon, or only a weakly developed one. However, clay eluviation and illuviation may be important processes in these soils. Only, these processes have not resulted yet in a clear Argillic B horizon. This group covers soils in different topographical positions and contains both *in situ* loess soils which lost their complete soil profile and secondary (colluvial) loess soils. Furthermore it contains soils with and without hydromorphic properties. On several locations the subsoil belonged to a different geological formation, like terrace gravel or limestone-derived flint stone and clay layers. These subsoils were often mixed up with material from the overlying loess layer. At about half of the locations gravel or stones occurred in the subsoil, starting between 40 and 120 cm. On three locations gravel or stones occurred within 40 cm, obviously as a result of the mixing of loess with other materials. At four locations the loess overlies clayey or sandy Tertiary marine deposits. Both the transition between the loess and the underlying material, and the presence of ground water can cause the observed hydromophic properties. The average organic matter content in the top soil (0-10 cm) was 4.4%. The average thickness of the humus layer was 4.7 cm.

Haplic and *Gleyic Luvisols* (FAO, 1988) or *Hapludalfs* and *Ochraqualfs* (USDA, 1975) were found in eleven of the 40 stands on loess soils. Extreme examples of the latter of both can also be classified as Gleyic Podzoluvisols or as Glossaqualfs, respectively. This group contains the Dutch 'Brik' (brick) soils. All four Dutch types of brick soils (cf. De Bakker & Schelling, 1989) are present in this group. The soils of three locations have been classified as Haplic Luvisols, of which two are 'Rade' brick soils and one is a 'Berg' brick soil. The soils of eight locations have been classified as Gleyic Luvisols, of which four are 'Kuil' brick soils and another four are 'Daal' brick soils. These soil types have in common the presence of an argillic B horizon, but differ in the extent they have been eroded and in the absence or presence and depth at which hydromorphic properties occur. The origin of, and the spatial relationships among these types have been discussed in Section 1.2 and Annex A.1. On a few locations a transition to a different material was found in the subsoil. The presence of this transition and the argillic B horizon can cause stagnation of percolating water, thus causing hydromorphic properties. All selected locations with Luvisols occur in loamy loess (< 50 μm fraction > 85%), although Luvisols also occur in sandy loess. The clay content in this parent material varied between 100 and 200 g kg^{-1}. The median clay content varied from 120 g kg^{-1} in the topsoil (0-10 cm) to 190 g kg^{-1} in the subsoil (60-100 cm) (Table 14). The average organic matter content in the topsoil (0-10 cm) was 3.9%. The average thickness of the humus layer was 4.5 cm.

Table 14 Median values (per depth and per soil type) of the estimated clay content and measured $CaCO_3$ contents of the loess soils

Depth	Clay contents (g kg^{-1})				$CaCO_3$ contents (g kg^{-1})			
	Eutric Cambisol sandy l.	Eutric Cambisol loamy l.	Haplic/ Gleyic Luvisol	Eutric/ Calcic Fluvisol	Eutric Cambisol sandy l.	Eutric Cambisol loamy l.	Haplic/ Gleyic Luvisol	Eutric/ Calcic Fluvisol[1]
0-10 cm	80	120	120	140	0.0	0.0	0.0	0.0
10-30 cm	80	125	120	160	0.0	0.0	0.0	0.0
30-60 cm	80	125	140	160	0.0	0.0	0.0	0.0
60-100 cm	90	135	190	155	0.0	0.0	0.0	0.0

[1] Mean values were respectively 0.5, 1.5, 0.0 and 0.0 g kg^{-1}.

Eutric and Calcaric Fluvisols (FAO, 1988) or *Udifluvents* (USDA, 1975) were found in four of the 40 stands on loess soils. This group contains the Dutch 'Polder' and 'Ooivaag' soils in fluvial clay. Two of the Eutric Fluvisols were found in Holocene fluvial deposits. One Eutric Fluvisol was found in Pleistocene fluvial deposits with a thin (colluvial) loess cover. One of the locations appeared to be calcareous, which caused the presence of one Calcaric Fluvisol in a set of non-calcareous soil types. This group consisted mainly of medium-textured clay soils with a high content of silt. The clay content (< 2 μm) varies between 120 and 250 g kg^{-1} and the loam content (< 50 μm) between 800 and 900 g kg^{-1}. The soils only consist of A and C horizons and either non-calcaric or calcaric throughout the profile (for eutric and calcaric fluvisols, respectively). The average organic matter content in the topsoil (0-10 cm) was 5.1%. The average thickness of the humus layer was 1.2 cm.

3.4.1.3 Soil types in clay

All nine different soil types (cf. De Bakker & Schelling, 1989) originally observed in the clay soils can all be classified as Eutric Fluvisols (FAO, 1988). In first instance, we clustered these soils into two groups: (1) the Eutric Fluvisols with a clay content of less than 35 percent (the medium-textured soils) and (2) the Eutric Fluvisols with a clay content of more than 35 percent (the fine-textured soils), cf. the field estimates of the clay content in Table 16. After the chemical analyses, a third group had to be distinguished, based on the carbonate content: the Calcaric Fluvisols.

All three tree species clusters are most common on the fine-textured Eutric Fluvisols (Table 15), although there are still differences. The pure poplar stands are almost completely concentrated on these soils. The two other clusters occur more often on the other soil types, especially the lighter textured Eutric Fluvisols.

Table 15 Distribution of the forest stands (per tree species) over the soil types in clay soils

Soil type	Poplar pure	Poplar mix	Other dec.	Total
Eutric Fluvisols - medium textured	1	3	3	7
Eutric Fluvisols - fine textured	7	4	8	19
Calcaric Fluvisols	1	2	1	4

Medium-textured *Eutric Fluvisols* (FAO, 1988) or *Fluvaquents* (USDA, 1975) were found in seven (originally nine) of the 30 stands on clay soils. This group contains the Dutch 'Poldervaag' soils with a clay content between 10 and 35 percent. One Eutric Cambisol (FAO, 1988), 'Ooivaag' soil (De Bakker & Schelling, 1989) or Fluvents (USDA, 1975) has been included in this group. The organic matter content in the topsoil (0-10 cm) was 6.0%, on average. The thickness of the humus layer was 0.8 cm, on average (maximum 3.9 cm).

Fine-textured *Eutric Fluvisols* (FAO, 1988) or *Fluvaquents* (USDA, 1975) were found in 19 (originally 21) of the 30 stands on clay soils. This group contains the Dutch 'Poldervaag' soils (De Bakker & Schelling, 1989) with a clay content between 35 and more than 60 percent. The organic matter content in the topsoil (0-10 cm) was 7.4%, on average. The thickness of the humus layer was 0.4 cm, on average (maximum 2.4 cm).

Four locations with fine-textured *Calcaric Fluvisols* (FAO, 1988) or *Fluvaquents* (USDA, 1975) were originally included in the previous two classes (two in each class), according to the information on the soil map. The presence of a significant amount of carbonates in the samples was the reason to consider these four location as a separate group. The clay contents is intermediate between the other groups. The median $CaCO_3$ content increased from ca 10 g kg^{-1} in the topsoil to ca 50 g kg^{-1} in the subsoil.

Table 16 Median values (per depth and per soil type) of the estimated clay content and measure $CaCO_3$ contents of the clay soils

Depth	Clay contents (g kg^{-1})			$CaCO_3$ contents (g kg^{-1})		
	Eutric Fluvisol med.-text.	Eutric Fluvisol fine-text.	Calcaric Fluvisol fine-text.	Eutric Fluvisol med.-text.	Eutric Fluvisol fine-text.	Calcaric Fluvisol fine-text.
0 - 10 cm	200	370	250	0.0	0.0	9.5
10 - 30 cm	210	440	283	0.0	0.0	14
30 - 60 cm	240	480	359	0.0	0.0	11
60 - 100 cm	220	520	370	0.0	1.0	51

3.4.1.4 Soil types in peat

The ten distinguished peat soil types (cf. De Bakker & Schelling, 1989) were to be classified either as Fibric Histosols or as Terric Histosol (cf. FAO, 1988), depending on properties of the topsoil. An extra indication of the difference between high moor and low moor locations was added. We clustered the soils into three groups: (1) Fibric Histosols in the low moor peat area, (2) Fibric Histosols in the high moor peat area, and (3) Terric Histosols in the high moor peat area. The clustering was done on the basis of differences in their expected vulnerability for acidification.

The stands with pure birch are almost equally distributed over the three distinguished soils types (Table 17). The stands with oak showed a certain coincidence with the Fibric Histosols in the High moor area, whereas the stands with and admixture of alder were more abundant in the low moor area. The coincidence of the occurrence of alder and low moor is related to the occurrence of alder as most common tree species in the low moor area. For the statistical analysis it is, however, relevant that this tree species (and all other tree species clusters) occur on all three distinguished soil types.

Table 17 Distribution of the forest stands (per tree species) over the soil types in peat soils

Soil type	Birch	Birch + oak	Birch + alder	Total
Fibric Histosol - High moor	4	6	1	11
Terric Histosol - High moor	3	4	2	9
Fibric Histosol - Low moor	5	2	3	10

Fibric Histosols (FAO, 1988) or *Sphagnofibrists* (USDA, 1975) in the high moor area were found in eleven of the 30 stands on peat soils. This group contains the Dutch 'Vlier' and 'Vliet' peat soils of the high moor area, which together form the 'raw' peat soils in the Dutch classification system (De Bakker & Schelling, 1989). The organic matter content in the topsoil (0-10 cm) was 94%, on average. The thickness of the humus layer was 2.9 cm, on average.

Terric Histosols (FAO, 1988) or *Medihemists* (USDA, 1975) in the high moor area were found in nine of the 30 stands on peat soils. This group contains the Dutch 'Made' and 'Koop' peat soils in the high moor area, which together form the 'earth' peat soils in the Dutch classification system (De Bakker & Schelling, 1989). The organic matter content in the topsoil (0-10 cm) was 83%, on average. The thickness of the humus layer was 2.4 cm, on average.

Fibric Histosols (FAO, 1988) or *Sphagnofibrists* (USDA, 1975) in the low moor area were found in ten of the 30 stands on peat soils. This group contains the Dutch 'Vlier' and 'Vliet' peat soils of the low moor area, which together form the 'raw' peat soils in the Dutch classification system (De Bakker & Schelling, 1989). At one location in the low moor area a Terric Histosol ('Made' peat soil cf. De Bakker & Schelling, 1989) was found, which was included in this group. The low moor characteristics are supposed to determine the soil chemical characteristics more than the differences between Fibric and Terric Histosols do. The organic matter content in the topsoil (0-10 cm) was 74%, on average. The thickness of the humus layer was 0.7 cm, on average.

3.4.2 Water-tables

Results on water-tables were classified in water-table classes according to the Dutch system (De Vries & Van Wallenburg, 1990) and clustered into drainage groups, as given in Table 18. The locations on loess soils were clustered in two groups and the locations on clay and peat soils in three groups.

Table 18 Clustering of the observed ground water level classes into drainage groups

Title	Ground water level classes	Mean extreme water-table [1] (cm)		Number
		Highest	Lowest	
<u>*Loess soils:*</u>				
Moist	V	0-40	> 120	6
Dry	VII, VIII (incl. VId)	> 120	> 120	34
<u>*Clay soils:*</u>				
Wet	III (including II)	0-40	80-120	8
Moist	V	0-40	> 120	9
Dry	VI (including VII)	> 40	> 120	13
<u>*Peat soils:*</u>				
Wet	I	0-25	0-50	14
Moderately drained	II and III	0-40	50-80	9
Excessively drained	IV, V, VI and VII	40-140	> 80	7

[1] generalized figures; for more details on the original classes see De Vries & Van Wallenburg (1990)

The group 'moist' locations on loess soils contains the six locations with water-table class V. These soils are wet in the spring, but deeply drained in the summer. The group 'dry' locations on loess soils contains the 34 locations with water-table classes VII and VIII. These soils are even in winter relatively well drained. The one location with the intermediate ground water level class VId has been included in this cluster, because it tends to be a dryer soil type.

Loess soils
A comparison of the distributions of the locations on loess soils over the tree species, the soil type and the drainage class shows a clear correlation among these distributions (Table 19). The moist soils occur mainly with the Gleyic Luvisols and the Fluvisols. The two types of Cambisols occur almost completely on dry locations. The 'other' deciduous species have a relatively strong connection with the 'moist' locations (Table 19). This group of species contains moist demanding species, such as poplar and alder. The correlations between the tree species and the soil types has already been shown in Table 13.

Table 19 Distribution of the forest stands on loess soils (per soil type and tree species) over the drainage classes

Drainage class	Soil type				Tree species			
	Eutric Cambisol sandy l.	Eutric Cambisol loamy l.	Haplic/ Gelyic Luvisol	Eutric/ Calcaric Fluvisol	Oak	Beech	Other deciduous	Conifers
Moist	0	1	3	2	1	0	4	1
Dry	8	16	8	2	18	7	5	3

Clay soils
The group 'wet' locations on clay soils contains the eight locations with water-table class III (Table 20). These soils are wet in the spring and moist in the summer, mostly still with capillary contact with the ground water. One wetter location with water-table class II has been included in this cluster. The group 'moist' locations on clay soils contain the nine locations with water-table class V. These soils are wet in the spring and dry in the summer. The group 'dry' locations on clay soils contains the 13 locations with water-table class VI. These soils are relatively well drained in the winter and mostly completely drained in summer. The three even dryer locations with water-table class VII have been included in this cluster.

Table 20 Distribution of the forest stands on clay soils (per tree species and soil type) over the drainage classes

Drainage class	Soil type			Tree species		
	Eutr.Fluvisol med-text.	Eutr.Fluvisol fine-text.	Calcaric Fluvisol	Poplar (pure)	Poplar (mix)	Other decid.
Wet	2	5	1	3	4	1
Moist	0	8	1	5	3	1
Dry	5	6	2	1	2	10

The comparison of the distributions of the locations on clay soils over the several tree species classes, soil type and water-table classes also shows correlations among these distributions. Most locations with medium-textured clay soils occur on the dry locations (Table 20), the rest in backswamp areas, within the area influenced by secondary loess sedimentation or near the rivers Meuse and Roer (the southernmost clay locations in Fig. 1). The amount of secondary loess made this sediment less fine than the sediment of other backswamp locations. Almost half of the fine-textured soils occur on moist soils. The rest are equally divided over the wet and the dry locations. The poplar stands mainly occur on the wet and moist locations, while the stands of 'other' deciduous species mainly coincide with the dry locations (Table 20).

Peat soils

On peat soils, the clustering of water-table classes is based on the extent of drainage compared with the original drainage conditions of peat soils (Table 21). Originally all peat soils were completely waterlogged, mostly even throughout the year. This wetness was (and is) the most important factor for the formation and existence of peat. Drainage leads to the physical and chemical degradation of the existing peat layer and stops the new-formation of peat. Half of the selected locations are still (originally or almost originally) wet (Table 18 and 21). Some locations are even flooded for several months per year. On other locations the surface layer is almost floating on the extremely watery subsoil, which implies that the water-table never drops deeper than 10 cm. These are the locations of which the drainage conditions resemble most the original drainage conditions of the peat lands. However, the system of water-table classes is not detailed enough to show the differences within water-table class I, i.e. between soils that are waterlogged all year, soils the are periodically flooded and soils that dry up superficially in the summer. These small differences are very important for the actual growth or degradation of the peat. The group of moderately drained peat soils are at least during part of the year superficially drained and aerated. Especially in summer these soils are drained unnaturally deep. The group of extremely drained peat soils have very low water-tables in either summer or winter or in both seasons.

The wet conditions occur on most locations in the low moor area (Table 21). More than half of the locations with terric Histosols in the high moor area are excessively drained and a considerable share are moderately drained. The Fibric Histosol in high moor have an intermediate distribution. This distribution shows that most locations in the low moor area are still very wet and that many of the locations in the high moor area have been drained. This drainage might be the main cause of the formation of the Terric topsoil of the locations in this area.

Table 21 Distribution of the forest stands on peat soils (per soil type) over the drainage classes

Drainage class	Soil type			Tree species		
	Fibr.Histosol high moor	Terr.Histosol high moor	Fibr.Histosol low moor	Birch	Birch + oak	Birch + alder
Wet	4	1	9	7	3	4
Mod. drained	5	3	1	3	4	2
Exc. drained	2	5	0	2	5	0

4 Chemical composition of the humus layer

In this chapter we give an overview of the characteristics of the humus layer[1], subdivided in contents and pools of (1) organic matter (also thicknesses and bulk densities) and nutrients, (2) exchangeable cations (including pH) and (3) heavy metals. First the variation in the observed data is given and then the influence of tree species and soil type is discussed.

4.1 Organic matter and nutrients

4.1.1 Organic matter, thickness and bulk density

4.1.1.1 Observed variation

Table 22 gives an overview of the thickness of the humus layer for all locations and the organic matter contents of the humus layer on the locations on loess and peat soils.

A humus layer was present in all forest stands on loess soils (except one meadow, which was excluded from the analysis) and in most of the forest stands on peat soils. In some stands on peat soils and in most stands on clay soils the amount of humus was too little to be sampled. This makes that the median value for the thickness of the humus layer on clay soils is 0 cm (Table 22).

The thickest humus layers occur on loess soils, with a range from nearly 0 to almost 10 cm. In most stands the humus layer consists only of L and F horizons. A high rate of decomposition on relatively fertile soils prevents the formation of an H horizon. Only on two locations an H horizon appeared to be thick enough (thicker than 1 cm) to be sampled separately. Therefore, the results of the H-layer are not presented separately, but are combined with the results of the L and F horizons in the overall results of the humus layer. The organic matter contents varies from 37 to 86%, which indicates that intermixing of the mineral top soil with the humus layer plays an important role on most locations.

In most stands on clay soils the humus layer consisted only of a little bit of loose, fresh leaves. Mostly it was not possible to measure the thickness of this loose material. On a few locations a humus layer occurred, though, with a maximum measured thickness of almost 4 cm. Hardly any F horizons and no H horizons were found. During the sampling period, when the growing season started, the thin humus layer disappeared rapidly as a result of the high rate of decomposition on these fertile soils. Therefore, only the actual thickness was measured and no samples were taken. No data can thus be presented on the pools and bulk densities of the humus layer

---

[1] The term 'humus layer' is used here as a compound for the complete ecto-organic soil profile, including the L (litter), F (fermentation) and H (humus) horizon.

of the locations on clay soils, neither on the chemical composition of the humus layer of these locations (Sections 4.1.2, 4.2 and 4.3).

A humus layer was also present in most of the stands on peat soils, although in nine stands the humus layer lacked or was too thin to be sampled, especially in the stands on 'growing peat' where the soil surface mostly consisted of *Sphagnum* mosses only. On some locations the humus layer consisted almost completely of dead grass (*Molinia caerulea*). The organic matter contents are high, and show a very narrow range between 900 and 970 g kg^{-1}, which can mainly be attributed to the absence of a mineral top soil.

The humus layers of all the three parent materials observed here, are thin to very thin, compared to the sandy soils (median value: 8.3 cm; De Vries & Leeters, 1999). For the loess soils, the organic matter contents of the humus layer compare very well with those found for the sandy soil, which vary between 240 and 900 g kg^{-1}, with a median value of 660 g kg^{-1} (De Vries & Leeters, 1999). For the peat soils, the organic matter contents are considerably higher.

Table 22 Minimum, maximum, 5th, 50th and 95th percentiles of the thickness and the organic matter contents the humus layer

Statistic	Thickness (cm)			Organic Matter (g kg^{-1}) [1]	
	Loess	Clay	Peat	Loess	Peat
Minimum	0.5	0.0	0.0	368	901
5th percentile	0.7	0.0	0.0	389	913
50th percentile	3.9	0.0	1.7	636	957
95 percentile	9.3	2.9	5.2	826	971
Maximum	9.8	3.9	6.0	856	972

[1] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Table 23 gives an overview of the variation in the estimated bulk densities and the calculated organic matter pools of the humus layer. Both include ('Layer') and exclude ('of O.M.' or 'Org. Mat') the amounts of mineral soil parts inside the samples, thus giving the values for the 'pure' organic matter. The correction was based on the organic matter content of the humus layer. The data for the bulk density of the humus layers on loess and peat soils are only based on the locations where a humus layer could be sampled. For the forest locations without an humus layer (nine locations on peat soils, for which no thickness or organic matter content were measured), the size of the pools was assumed to be 0.

For the loess soils, the bulk density of organic matter in the humus layer varies between 12 and 112 kg m^{-3} (Table 23). The pools of organic matter in the humus layer varies between 2 and 99 ton ha^{-1}, with a median value of 22 ton ha^{-1}. The reason of this wide range can be found in the reinforcement of thickness and bulk density of the humus layer. Where a thin humus layer occurs, it mostly consist of relatively young, loose litter only. Where a thicker humus layer occurs, it is often further decomposed and compacted and sometimes containing an H horizon.

For the peat soils, the pools of organic matter in the humus layer varies between 0.0 and 91 ton ha^{-1}, with a median value of 25 ton ha^{-1} (Table 23). The bulk density of the organic matter of the humus layer (on the locations where it was present) did hardly show any variation: only between 150 and 152 kg m^{-3}.

The bulk density of the organic matter in the humus layer of loess soils is lower than for the sandy soils (77 kg m^{-3}; De Vries & Leeters, 1999), whereas for the peat soils it is higher. Compared to the non-calcareous sandy soils (median value 66 ton ha^{-1}), the pools of organic matter in the humus layer for loess, clay and peat soils are small.

Table 23 Minimum, maximum, 5th, 50th and 95th percentiles of bulk density and organic matter pools of the humus layer

Statistic	Bulk density (kg m^{-3})				Pools (ton ha^{-1})			
	Loess		Peat		Loess		Peat	
	Layer	of O.M.	Layer	of O.M.	Layer	Org.Mat.	Layer	Org.Mat.
Minimum	16	12	156	150	2.7	1.8	0.0	0.0
5th percentile	26	19	156	151	3.6	2.1	0.0	0.0
50 percentile	94	55	158	152	41	22	27	25
95 percentile	184	103	165	152	142	65	83	79
Maximum	201	112	167	152	146	99	98	91

[1] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

4.1.1.2 Relations with the environmental characteristics

Tree species

Within the loess soils, the thickness and organic matter pools of the humus layer are clearly influenced by the tree species (Table 24). The thickest humus layers and largest pools occur under 'beech' and 'conifers'. The thinnest humus layers and smallest pools occur under 'other deciduous species'. The cluster 'other deciduous' on loess soils contains a number of poplar stands, which are known to have a very quick decomposition of the litter. On clay soils the median thickness of the humus layer under 'other deciduous species' (i.e. oak, beech, etc.) is also slightly thicker than under 'poplar' (0.5 vs. 0.0 cm). The humus layer under 'oak' has the largest admixture of mineral soil parts (40%). The bulk density is largest for 'conifers' and smallest for 'other deciduous species'.

Within the peat soils, the thickest humus layers were found under 'Birch+oak' and no or hardly any humus layer was found under 'Birch+alder'. The first indicates that the presence of oak may be related to conditions with hampered decomposition of fallen leaves. The latter indicates that the presence of alder may be related to better conditions, either by seepage water of by the impact of alder itself.

Soil types

Within the loess soils, the median thickness and the pools of the humus layer are largest for the Cambisols in sandy loess and somewhat smaller for the Cambisols in loamy loess and for the Luvisols (Table 25). Thickness and pools for Fluvisols are much smaller than for the other soil types, which proves the similarity of these soils with the 'ordinary' Fluvisols in fluvial clay soils.

Table 24 Median values of the thickness, organic matter contents, bulk density and organic matter pools of the humus layer as a function of the tree species [1].

Tree species [2]	Thickness (cm)	Org. Mat. (g kg^{-1})	Bulk dens. (kg m^{-3})		Pools (ton ha^{-1})	
			Layer	Org. Mat.	Layer	Org.Mat.
Loess soils:						
Oak	4.0	628	97	56	42	21
Beech	5.9	605	80	55	51	34
Other deciduous	1.7	665	78	47	11	8.0
Conifers	5.6	677	102	66	57	37
Expl. variance (% R^2_{adj})	*28*	*0*	*0*	*0*	*16*	*17*
Peat soils:						
Birch	1.6	964	157	152	21	20
Birch + oak	3.1	949	160	151	49	46
Birch + alder	0.0	960	158	152	0.0	0.0
Expl. variance (% R^2_{adj})	*12*	*0*	*0*	*3*	*9*	*9*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.
[2] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Table 25 Median values of the thickness, organic matter contents, bulk density and organic matter pools of the humus layer as a function of the soil type [1].

Soil type [2]	Thickness (cm)	Org. Mat. (g kg^{-1})	Bulk dens. (kg m^{-3})		Pools (ton ha^{-1})	
			Layer	Org. Mat.	Layer	Org.Mat.
Loess soils:						
Cambisol in sandy loess	5.9	533	97	54	57	31
Cambisol in loamy loess	3.7	665	86	56	37	21
Haplic and Gleyic Luvisol	4.7	659	96	59	47	28
Eutric and Calcic Fluvisol	1.0	571	74	34	4.8	2.9
Expl. variance (% R^2_{adj})	*23*	*0*	*0*	*3*	*19*	*22*
Peat soils:						
Fibric Histosol, high moor	3.3	962	158	152	52	50
Terric Histosol, high moor	2.3	945	160	151	38	36
Fibric Histosol, low moor	0.8	964	157	152	4.3	4.2
Expl. variance (% R^2_{adj})	*6*	*5*	*5*	*3*	*12*	*12*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.
[2] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Within the peat soils, the thickness and the pools of the humus layer are smallest for the locations in the low moor area (Table 25). In this cluster the largest number was found of locations with 'living peat', on which litter fall disappears in the growing sphagnum mosses. On other locations in this cluster temporary flooding causes the removal and quick decomposition of the fresh litter. The humus layers in the high moor area are much thicker, with the largest humus accumulation on the Fibric Histosols. On the Terric Histosols decomposition is better than on the Fibric Histosols, because of the better drainage status of these soils (Section 3.4). This even compensates for a number of locations on Fibric Histosols in the high moor area, where hardly any humus layer is present because of growing peat conditions.

Statistical analysis

The elements of the simple explanatory model (i.e. soil type and tree species) are generally not very relevant for the explanation of the variation in the thickness, bulk densities and pools of the humus layer on loess and peat soils (Table 26). Only the thickness of the humus layer on loess soils shows a satisfactory correlation with the combination of soil type and tree species. The thickness of the humus layer on clay soils is only weakly correlated with the tree species, both in the simple and the complete model.

The extension of the model with all other environmental characteristics shows that the deposition levels and the position of the forest stand are important additional factors for the humus layer measures on loess soils (Table 26). The amounts of humus is larger and the layer is more compact with increasing deposition levels and with increasing distance to the forest edge. The former indicates that atmospheric deposition may contribute to enhanced accumulation of a humus layer in these forest and the latter indicates that part of the litter is blown away close to forest edges. Furthermore, the amount and compactness of the humus layer seems negatively correlated with the tree height. This pattern might be related to the period of accumulation, since tree height is, at least partly, a function of the tree age.

Table 26 Best explaining environmental characteristics for the thickness, the organic matter contents, the bulk density and the organic matter pools of the humus layer, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	$\%R^2_{adj}$	Sign.[3]	Factors	$\%R^2_{adj}$	Sign.[3]
Loess soils:						
Thickness	So + Tr	35	***	So + Tr	35	***
Org.matter content	-	0	-	-	0	-
Bu.density - Layer	-	0	-	Ds + Dp_t + He	25	**
- Org. Mat.	So	3	-	Dp_t + He + Ds	38	***
Pools - Layer	So + Tr	22	*	Dp_{nh} + Ds	44	***
- Org.Mat	So + Tr	26	*	Dp_t + Ds + He	53	***
Clay soils:						
Thickness	Tr	10	*	Tr	10	*
Peat soils:						
Thickness	So + Tr	13	-	Tr	12	*
Org.matter content	So	5	-	-	0	-
Bu.density - Layer	So	5	-	-	0	-
- Org.Mat	So	3	-	La	66	***
Pools - Layer	So + Tr	16	*	So + La + Dp_{so}.So	58	***
- Org.Mat.	So + Tr	16	*	So + La + Dp_{so}.So	57	***

[1] Simple model: analysis only with 'Tree species' and 'Soil Type' (coding cf. Section 2.4).
[2] Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).
[3] Significance: - = ($p \geq 0.1$), * = ($p < 0.1$), ** = ($p < 0.01$), *** = ($p < 0.001$)

The extension of the model did not result in a better model for explanation of the variation in the thickness and organic matter contents of the humus layer on peat soils (Table 26). The explanation of the variation in the pools, however, and also of the bulk density of the organic matter is significantly improved by the addition of the nearest land use type as explanatory factor. The reason for this inclusion is unclear. This factor might either be a good local indicator for the quality of the land of have important local impacts on the humus accumulation. The amounts are positively correlated with the deposition levels on the Fibric Histosols in the high moor area, whereas no such relationship was found for the other soil types. This relationship, however, might be obscured by the correlation between soil type and land use type.

4.1.2 Organic carbon and nutrients

4.1.2.1 Observed variation

The contents of the various nutrients in the humus layer can be expressed as absolute values, as well as in percentages of the organic matter (Table 27 and 28, respectively). The expression in percentage of the organic matter content is relevant for those elements that are strongly involved in the nutrient cycling and for which the contents in the humus layer mainly result from litterfall. The is primarily the case for C and N, but, in a decreasing order, also partly for P, S, Ca, Mg and K. The contents of Al, Fe and Mn are mainly related to the admixture of particles from the underlying subsoil, whereas the Na content is also affected by atmospheric deposition of this element. The contents of the elements that are mainly related to the underlying soil, are not expressed as relative values to the organic matter content.

The contents of C and N in the humus layer of the peat soils is generally higher for the peat soils than for the loess soils (Table 27). This is, however, probably related to the higher organic matter content of the humus layer on peat, since the values are generally higher for loess soils after correction for the organic matter content (Table 28). The only slightly less favourable 'absolute' contents of P, Ca, Mg and K in the peat soils appear considerably worse after the correction for the organic matter content. Na is the only element with higher values for the peat soils. This probably related to the larger proportion of location is in the western part of the country, with higher Na deposition, and possibly also some influence of Na containing surface water or seepage water. The higher content of Al and Fe in the loess soils is probably related to the admixture of particles from the mineral topsoil.

For the loess soils, the C and N contents of the humus layer are in the same range as for sandy soils (N: 1.5-3.0%, median value 2.2%, De Vries & Leeters, 1999). The P, S, Ca and K contents are higher than for the sandy soils, but the Mg contents are lower. For the peat soils the C, N, P, Ca and Mg contents are lower than for the sandy soils, but the K contents are higher. This indicates that the loess soils are generally richer than the sandy soils. However, Mg deficiency in forests on loess soils may be at least as common as in forests on sandy soils. The peat soils are generally poorer that the sandy soils. However, all element occur at a low level, except N, which also showed a considerable number of high values. This indicates that N accumulation in the humus layer might cause serious nutrient imbalances on the peat soils.

Table 27 Minimum, maximum, 5th, 50th and 95th percentiles of total nutrient contents in the humus layer ($g\ kg^{-1}$)

Statistic [1]	C	N	P	S	Ca	Mg	K	Na	Al	Fe	Mn
Loess soils:											
Minimum	211	10	0.60	1.5	1.6	0.54	0.97	0.03	1.3	1.8	0.06
5th percentile	227	10	0.60	1.7	1.8	0.55	1.1	0.03	3.1	3.4	0.07
50th percentile	341	15	0.80	2.3	3.7	0.98	2.0	0.04	6.6	6.3	0.18
95th percentile	432	21	1.6	3.0	18	2.1	3.4	0.07	12	12	2.7
Maximum	454	21	1.6	3.3	19	2.2	4.0	0.07	14	13	3.9
Peat soils:											
Minimum	371	18	0.53	-	1.5	0.55	0.56	0.03	0.37	0.94	-
5th percentile	385	19	0.57	-	1.9	0.62	0.63	0.04	0.42	0.96	-
50th percentile	443	23	0.75	-	3.6	0.90	0.89	0.06	1.3	2.0	-
95th percentile	497	27	1.2	-	5.4	1.4	1.5	0.21	2.2	4.7	-
Maximum	502	27	1.3	-	5.5	1.4	1.7	0.28	2.2	5.2	-

[1] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Table 28 Minimum, maximum, 5th, 50th and 95th percentiles of total nutrient contents in the humus layer , expressed in percentage of the organic matter ('% O.M.')

Statistic [1]	C	N	P	S	Ca	Mg	K	Na
Loess soils:								
Minimum	45	1.5	0.07	0.23	0.24	0.07	0.12	0.00
5th percentile	47	2.0	0.08	0.27	0.31	0.07	0.13	0.00
50th percentile	54	2.5	0.14	0.37	0.59	0.17	0.32	0.01
95th percentile	62	3.0	0.23	0.49	2.7	0.38	0.69	0.01
Maximum	64	3.1	0.31	0.52	3.8	0.48	0.94	0.02
Peat soils:								
Minimum	39	1.9	0.06	-	0.16	0.06	0.06	0.00
5th percentile	40	2.0	0.06	-	0.19	0.06	0.06	0.00
50th percentile	48	2.5	0.08	-	0.38	0.09	0.09	0.01
95th percentile	51	2.8	0.13	-	0.59	0.15	0.15	0.02
Maximum	52	2.9	0.14	-	0.61	0.15	0.18	0.03

[1] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Table 29 gives an overview of the variation in the nutrient pools (N and P) and the nutrient ratios in the humus layer on loess and peat soils. For the forest locations without a humus layer (nine locations on peat soils, for which no contents were measured), the size of the nutrient pools was assumed to be 0. The pools of N and P in the humus layer of loess and peat soils show very wide ranges. The median N pool is larger for peat soils, but both the minimum and maximum values are higher for loess soils. The P pools are larger for the loess soils over the whole range. The C/N ratios are higher for the loess soils, whereas the C/P and N/P ratios are higher for the peat soil.

For both the loess and the peat soil, the N and P pools in the humus layer are smaller than for the sandy soils (De Vries & Leeters, 1999), which can mainly be ascribed to the greater thickness of the humus layer on sandy soils. The C/N and C/P ratios for both the loess and peat soils are lower than for the sandy soils (median values for the sandy soils: 26 and 714, respectively). The N/P ratios of the sandy soils lay between those of the loess soils and the peat soils: the loess soils have lower N/P ratios and the peat soils have higher N/P ratios than the sandy soils.

Table 29 Minimum, maximum, 5th, 50th and 95th percentiles of total nutrient pools and ratios in the humus layer

Statistic [1]	Nutrient pool (kg ha^{-1})			Nutrient ratio (kg kg^{-1})		
	C	N	P	C/N	C/P	N/P
Loess soils:						
Minimum	937	44	3.3	16	165	7.7
5th percentile	1 097	53	3.4	17	227	11
50th percentile	11 660	579	33	21	360	17
95th percentile	37 731	1 593	106	28	693	32
Maximum	55 328	2 312	117	38	757	34
Peat soils:						
Minimum	0.0	0.0	0.0	15	343	19
5th percentile	0.0	0.0	0.0	16	367	19
50th percentile	12 093	642	24	19	588	33
95 percentile	39 281	2 150	61	24	776	40
Maximum	40 452	2 263	98	25	822	41

[1] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

4.1.2.2 Relations with the environmental characteristics

Tree species

Within the loess soils, the humus layers under 'oak' and 'beech' have equal contents of N, P, S, Ca, Mg and K and equal C/N ratios. For the 'other deciduous species', the contents of these elements are higher (Table 30). For 'conifers' N, P and S contents are comparable to 'oak' and 'beech', but the Ca, Mg and K contents are lower and the C/N ratio higher. The C content does not seem to depend on the tree species. The pools of (accumulated) N increase from 'Other deciduous' < 'Oak' < 'Conifers' < 'Beech', thus reflecting the same trend in the organic matter pools.

Within the peat soils, the lowest contents of P and base cations (Ca, Mg and K) were found under pure birch stands (Table 30). This indicates that the pure birch stand have poorer conditions than the stands mixed with oak or alder. The absence of differences in N content and C/N ratio, however, indicates that this difference in poorness does not apply for the N nutrition from the humus layer. The differences in N pool reflect mainly the differences in amounts of the humus layer (Table 24).

Soil types

Within the loess soils, the P, S, Ca, Mg and K contents of the humus layer show a clear increase from sandy loess Cambisols < loamy loess Cambisols < Luvisol < Fluvisols (Table 31). As with the tree species, this trend is not reflected in the C contents. Neither is this trend found for the N contents, although the highest N contents are still found for the Fluvisols, whereas the highest C/N ratios are found for the Luvisols. Within the peat soils, the N contents of the humus layer are higher in the high moor soils than in the low moor soil types, which is also reflected in the increase in C/N ratios. The Ca and Mg contents also increase in the presented order. There are only slight differences among the observed C, P and K concentrations.

Within the peat soils, the P, Ca, Mg and K contents show an increase in the presented order of soil types, whereas the N contents and especially the N pools show a decrease.

Table 30 Median values of total nutrient contents in organic matter of the humus layer as a function of the tree species [1)].

Tree species [2)]	Nutrient content (% of organic matter)							N pool (kg ha^{-1})	C/N ratio (kg kg^{-1})
	C	N	P	S	Ca	Mg	K		
Loess soils:									
Oak	54	2.5	0.13	0.35	0.55	0.15	0.31	560	21
Beech	51	2.4	0.13	0.33	0.51	0.15	0.31	853	21
Other deciduous	53	2.8	0.20	0.40	1.4	0.23	0.36	149	20
Conifers	57	2.3	0.11	0.34	0.36	0.10	0.23	761	25
Expl. variance (% R²adj)	*5*	*0*	*28*	*0*	*43*	*9*	*0*	*15*	*7*
Peat soils:									
Birch	47	2.5	0.07		0.34	0.09	0.09	494	20
Birch + oak	48	2.5	0.09		0.40	0.10	0.09	1 269	19
Birch + alder	48	2.4	0.09		0.42	0.11	0.11	0.0	20
Expl. variance (% R²adj)	*0*	*0*	*6*		*0*	*0*	*0*	*9*	*0*

1) Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.
2) No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Table 31 Median values of total nutrient contents in organic matter of the humus layer as a function of the soil type [1)].

Soil type [2)]	Nutrient content (% of organic matter)							N pool (kg ha^{-1})	C/N ratio (kg kg^{-1})
	C	N	P	S	Ca	Mg	K		
Loess soils:									
Cambisol in sandy loess	54	2.5	0.11	0.34	0.39	0.12	0.28	761	22
Cambisol in loamy loess	51	2.4	0.13	0.35	0.59	0.15	0.30	541	20
Haplic+Gleyic Luvisol	57	2.5	0.17	0.38	0.93	0.22	0.41	702	23
Eutric+Calcaric Fluvisol	53	2.6	0.21	0.40	2.1	0.35	0.56	84	20
Expl. variance (% R²adj)	*0*	*0*	*17*	*0*	*31*	*19*	*13*	*24*	*0*
Peat soils:									
Fibric Histosol, high m.	49	2.6	0.07	-	0.31	0.08	0.09	1 337	19
Terric Histosol, high m.	48	2.5	0.09	-	0.50	0.11	0.09	1 015	19
Fibric Histosol, low. m.	47	2.1	0.09	-	0.54	0.12	0.11	85	21
Expl. variance (% R²adj)	*0*	*14*	*27*	-	*21*	*24*	*32*	*12*	*8*

1) Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.
2) No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Statistical analysis

For the loess soils, the P and Ca contents of the humus layer are explained well by the separate factors soil type and the tree species (Table 32, in comparison with Tables 30 and 31). The same predictors give only a weakly significant explanation in the variation in the Mg and K contents and the N pool.

The extension of the model with all other environmental characteristics shows that the C and S contents in the humus layer of the loess soils are not correlated with any of these factors (Table 32). The N contents and the C/N ratio are correlated with the land use type, whereas the N pool is correlated with the deposition levels and the distance to the forest edge. The results for the N contents and the C/N ratio indicate that the N emissions from the adjacent agricultural area are more important for the N variable of the humus layer than regional deposition levels. The highest N contents were found for stands bordered by maize lands.

The contents of P and base cations (Ca, Mg and K) is negatively correlated with deposition levels (especially of total acidity) (Table 32). This indicates that these elements are leached from the humus layer, due to atmospheric deposition and consequent acidification. The positive correlation between the Ca and P contents and the tree height indicates that the better supply of these elements has a positive impact on tree growth. The base cation contents are also correlated with the position of the stand and seem also negatively correlated with the distance to the forest edge. This indicates that enhanced base cation deposition close to forest edges may also play a role.

Table 32 Best explaining environmental characteristics for the total nutrient contents in the organic matter of the humus layer, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	$\%R^2_{adj}$	Sign.[3]	Factors	$\%R^2_{adj}$	Sign.[3]
<u>*Loess soils:*</u>						
C	So + Tr	7	-	-	0	-
N	-	0	-	La	24	**
P	So + Tr	32	**	Tr + Dp_t + He	52	***
S	-	0	-	-	0	-
Ca	So + Tr	52	***	Tr + Dp_t + He + Ds	77	***
Mg	So + Tr	20	*	Tr + Dp_t + Di + Dr	54	***
K	So	13	*	So + Dp_t + Dr + Di	45	***
N pool	So + Tr	26	*	Dp_{nh} + Ds	49	***
C/N ratio	Tr	7	-	La	37	***
<u>*Peat soils:*</u>						
C	-	-	-	Dp_{nh} + Di	43	**
N	So	14	*	So	14	*
P	So + Tr	47	**	So + Tr	47	**
S						
Ca	So + Tr	22	*	So + La	48	**
Mg	So	24	*	So	24	*
K	So	32	*	So + Di + Ca	57	**
N pool	So + Tr	16	*	So + La + Dp_{so}.So	57	***
C/N ratio	So	8	-	Dr_c	15	*

[1] Simple model: analysis only with 'Tree species' and 'Soil Type' (coding cf. Section 2.4).
[2] Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).
[3] Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

For the peat soils, the regression analysis with the simple model with the soil type only, shows only weak correlations (Table 32). The best correlation was found for the P contents with the combination of the soil type and the tree species.

The extension the model with all other environmental characteristics reveals hardly any deposition variables as important predictors for the nutrient contents of the humus layer on peat soils (Table 32). The C content is negatively correlated with the deposition level of NH_x and the N pool on Fibric Histosols in the high moor area is positively correlated with the SO_x deposition level. The latter is, however, closely related to the same pattern for the humus amounts (Table 26). The land use type bordering the forest stand is important for the Ca contents and the N pools. The lowest Ca contents were found at locations bordering grass lands. The locations bordering arable land (not maize) show the highest Ca contents and also the lowest N pools. The variation in K contents is also explained by the stand characteristics direction of the forest edge and canopy closure. The C/N ratio shows an decrease with increasing drainage, which indicate better condition when the soils become dryer.

4.2 pH and cation exchange characteristics

4.2.1 pH(H_2O) and pH(KCl)

4.2.1.1 Observed variation

The observed values for the pH(H_2O) and pH(KCl) of the humus layer on loess and peat soils show a normal distribution (Table 33). The median values and lower percentiles of the pH(H_2O) and pH(KCl) of the humus layer are equal for loess and peat soils. At the upper end of the ranges there is, however, a striking difference between loess and peat soils. The maximum pH(H_2O) for peat soils is 4.8, while it is 6.4 for loess soils. The maximum pH(KCl) for loess soils is even 6.6, indicating that the amount of exchangeable H is close to 0.

Table 33 Minimum, maximum, 5th, 50th and 95th percentile of the pH(H_2O) and the pH(KCl) for the humus layer

Statistic [1]	pH(H_2O)		pH(KCl)	
	Loess	Peat	Loess	Peat
Minimum	3.8	3.8	2.9	3.0
5th percentile	3.9	3.8	3.0	3.0
50th percentile	4.3	4.2	3.5	3.4
95th percentile	6.4	4.7	6.2	4.0
Maximum	6.4	4.8	6.6	4.1

[1] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

In the range between minimum and median, the values for loess and peat soils are approximately 0.5 unit higher than the values found for the humus layer of sandy soils (De Vries & Leeters, 1999). At the upper end of the range, the values for the loess soils are more than 1 unit higher than for the sandy soils. For the peat soils these values are slightly lower than for the sandy soils.

4.2.1.2 Relations with the environmental characteristics

Tree species

Within the loess soils, the pH values in the humus layer are much higher for the 'other deciduous species' than for 'oak', 'beech' and 'conifers' (Table 34). The values for 'conifers' are slightly lower than for 'oak' and 'beech'. Within the peat soils, the pH values in the humus layer are slightly higher for the sites with alder, compared with the two other clusters.

Table 34 Median values of the pH(H_2O) and the pH(KCl) for the humus layer as a function of the tree species [1]*.*

Tree species [2]	pH(H_2O)		pH(KCl)
<u>*Loess soils:*</u>			
Oak	4.2		3.3
Beech	4.2		3.4
Other deciduous	5.6		5.2
Conifers	4.0		3.0
Expl. variance (% R^2_{adj})	*34*		*38*
<u>*Peat soils:*</u>			
Birch	4.2		3.5
Birch + oak	4.2		3.3
Birch + alder	4.3		3.6
Expl. variance (% R^2_{adj})	*0*	*0*	*0*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

[2] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Soil types

Within the loess soils, the pH values of the humus layer are lowest on sandy loess Cambisols. The Fluvisols have the highest pH values and the difference between pH(H_2O) and pH(KCl) is only 0.1 (Table 35), which indicates that the median H saturation of these soils is almost 0. This cluster fully contributes for the found maximum values in Table 33. Within the peat soils, the most acidic humus layers are observed on the Fibric Histosols in the high moor area. On the contrary, the least acidic humus layers are observed the Fibric Histosols in the low moor area, which might be due to the weak influence of the nearby mesotrophic surface water.

The values for the pH of the humus layer of the most acidic loess and peat soils differ little from the values found for sandy soils (3.8 and 2.8, respectively, De Vries & Leeters, 1999).

Table 35 Median values of the pH(H_2O) and the pH(KCl) for the humus layer as a function of the soil type [1].

Soil type [2]	pH(H_2O)	pH(KCl)
Loess soils:		
Cambisol in sandy loess	4.1	3.1
Cambisol in loamy loess	4.3	3.6
Haplic and Gleyic Luvisol	4.4	3.7
Eutric and Calcic Fluvisol	6.1	6.0
Expl. variance (% R^2_{adj})	*30*	*36*
Peat soils:		
Fibric Histosol, high moor	4.1	3.1
Terric Histosol, high moor	4.3	3.5
Fibric Histosol, low moor	4.5	3.7
Expl. variance (% R^2_{adj})	*19*	*24*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

[2] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Statistical analysis

For the loess soils, the simple model for the multiple regression shows that the soil type and the tree species together explain about half of the variance in the pH values (Table 36), but that these factors separately also account for a relatively large percentage of accounted variance (Tables 34 and 35). The extension of the statistical model with all other environmental factors results in the addition of the deposition level, the tree height and the distance to the forest edge as significantly explaining variables. The pH values are negatively correlated with the deposition levels and the distance to the forest edge and positively correlated with the tree height. The correlation with the deposition levels indicates that the humus layers are directly affected by atmospheric deposition. The positive impact of the proximity of the forest edge might be related to the buffering effect of deposition of base cations. The positive correlation with the tree height is probably an indication of the positive effect of higher pH values on the forest growth.

Table 36 Best explaining environmental characteristics for the pH(H_2O) and the pH(KCl) for the humus layer, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	%R^2_{adj}	Sign.[3]	Factors	%R^2_{adj}	Sign.[3]
Loess soils:						
pH(H_2O)	So + Tr	44	***	Tr + Dp_t + He + Ds	67	***
pH(KCl)	So + Tr	51	***	Tr + Dp_t + He + Ds	71	***
Peat soils:						
pH(H_2O)	So	19	*	So	19	*
pH(KCl)	So	24	*	So	24	*

[1] Simple model: analysis only with 'Tree species' and 'Soil Type' (coding cf. Section 2.4).

[2] Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).

[3] Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

For the peat soils, both the simple and the full statistical model yield in only the soil type as a relevant explaining factor for the differences in pH values in the humus layer (Table 36). This indicates that only the soil type has a weakly significant influence on the pH values in the humus layer and that any influence by the deposition levels can not be proved.

4.2.2 Cation exchange capacity (CEC)

4.2.2.1 Observed variation

Table 37 gives an overview of the variation of the cation exchange capacity (CEC) of the humus layer on loess and peat soils. The CEC is expressed both per kg of humus (including mineral particles) and per ha, as well as per kg organic matter in the organic matter, CEC(O.M.). In this calculation it is assumed that the CEC is completely due to the organic matter. For the forest locations without an humus layer (nine locations on peat soils, for which no concentrations were measured), the size of the CEC per ha was assumed to be 0.

The results for the CEC of the humus layer (Table 37) show rather wide distributions, both for loess and peat soils. For loess soils the distribution is rather skew. For peat soils the distribution is more normal and the difference between the numbers before and after the correction for the organic matter content are small.

Table 37 Minimum, maximum, 5th, 50th and 95th percentiles of the CEC of the humus layer

Statistic [1]	CEC content (mmol$_c$ kg^{-1})						CEC pool (kmol$_c$ ha^{-1})	
	measured		in Org.Matter		in O.M.$_{pH(KCl)=6.5}$			
	Loess	Peat	Loess	Peat	Loess	Peat	Loess	Peat
Minimum	222	314	392	326	-	517	1.5	0.0
5th percentile	236	317	420	329	-	545	1.8	0.0
50th percentile	334	423	578	437	-	804	12	12
95th percentile	764	522	1 044	572	-	927	36	30
Maximum	806	532	1 211	572	-	934	44	45

[1] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

The values found for loess soils are higher than those found in sandy soils (between 240 and 800 mmol$_c$ kg^{-1} in the organic matter, with a median value of 470 mmol$_c$ kg^{-1}; De Vries & Leeters, 1999). However, the CEC per ha is much higher for sandy soils: between 5.0 and 73 kmol$_c$ ha^{-1}, with a median value of 30 kmol$_c$ ha^{-1}. The greater thickness of the humus layer on sandy soils obviously fully compensates the smaller CEC per kg.

4.2.2.2 Relations with the environmental characteristics

Tree species

Within the loess soils, the lowest CEC values (measured and in the organic matter) were found for 'other deciduous' (Table 38). The differences between the CEC values for the various tree species are, however, probably mainly related to the dependency of the CEC with the pH, since there are no significant differences in the CEC at a standard pH. Only the values for beech are still lower than for the other tree species clusters.
The CEC pools reflect strongly the pools of organic matter.

Within the peat soils, only little variation is found in the CEC values between the various tree species (Table 38). The values for the cluster with oak are slightly higher than for the other clusters, even after the correction for the pH dependency of the CEC. The differences in CEC pool mainly reflect the differences in amounts of the humus layer.

Table 38 Median values of the CEC of the humus layer as a function of the tree species [1].

Tree species [2]	CEC content ($mmol_c\ kg^{-1}$)			CEC pool ($kmol_c\ ha^{-1}$)
	measured	in Org.Mat.	in $O.M._{pH(KCl)=6.5}$	
Loess soils:				
Oak	326	578	1 035	12
Beech	339	470	929	19
Other deciduous	494	719	1 012	4.6
Conifers	302	446	1 001	16
Expl. variance (% R^2_{adj})	*21*	*25*	*0*	*10*
Peat soils:				
Birch	408	430	780	9.8
Birch + oak	442	465	868	22
Birch + alder	402	420	732	0.0
Expl. variance (% R^2_{adj})	*0*	*0*	*0*	*10*

1) Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

2) No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Soil types

Within the loess soils, the CEC (both measured and in the organic matter) increases regularly from the Sandy Loess Cambisols towards the Fluvisol (Table 39). Corrected for the differences in pH, however, the lowest values appear for the loamy loess Cambisols. The CEC pool decreases in the presented order, due to the strong decrease in the thickness of the humus layer. Also within the peat soils, the values show an increase for the CEC in the presented order, and a decrease in the CEC pools. Corrected for the differences in pH, however, the highest values are found for the Terric Histosols.

Table 39 Median values of the CEC of the humus layer as a function of the soil type [1].

Soil type [2]	CEC content ($mmol_c\ kg^{-1}$)			CEC pool ($kmol_c\ ha^{-1}$)
	measured	in Org.Mat.	in $O.M._{pH(KCl)=6.5}$	
Loess soils:				
Cambisol in sandy loess	306	530	1 112	18
Cambisol in loamy loess	332	559	982	12
Haplic and Gleyic Luvisol	334	582	1 097	14
Eutric and Calcaric Fluvisol	523	927	1 022	3.0
Expl. variance (% R^2_{adj})	*4*	*13*	*7*	*19*
Peat soils:				
Fibric Histosol, high moor	396	410	780	24
Terric Histosol, high moor	432	452	826	15
Fibric Histosol, low moor	446	461	707	1.8
Expl. variance (% R^2_{adj})	*1*	*2*	*0*	*11*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

[2] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Statistical analysis

Both for the loess soils and for the peat soils, the values for the CEC show only slight correlations with the soil type and/or the tree species (Table 40). Extension of the statistical model with all other environmental characteristics yields in the addition of the tree height and the deposition level as important explaining factors for the CEC of the organic matter for the loess soils. This relationship, however, seems mostly determined by the pH dependency of the CEC, since no relationship could be found after standardization to a fixed pH level.

Table 40 Best explaining environmental characteristics for the CEC of the humus layer, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	%R^2_{adj}	Sign.[3]	Factors	%R^2_{adj}	Sign.[3]
Loess soils:						
CEC - measured	Tr	21	*	Tr + He	29	**
- in Org.Mat.	So + Tr	27	*	Tr + Dp_t + He	52	***
- in O.M./pH6.5	So	7	-	-	0	-
CEC pool	So	19	*	Dp_{nh} + Ds	44	***
Peat soils:						
CEC - measured	So	1	-	-	0	-
- in Org.Mat.	So	2	-	-	0	-
- in O.M./pH6.5	-	0	-	Dr_c	16	*
CEC pool	So + Tr	15	*	So + La + Dp_{so}.So	57	**

[1] Simple model: analysis only with 'Tree species' and 'Soil Type' (coding cf. Section 2.4).

[2] Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).

[3] Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

The CEC values for the peat soils (both measured and in the organic matter) do not show any significant relationship (Table 40). The CEC values at a standard pH show a weakly significant positive relationship with the drainage class. The explaining a weakly significant positive relationship with the drainage class. The explaining model for the CEC pool, both on loess and peat soils, are largely determined by the model for the humus amounts (Table 26).

4.2.3 Exchangeable cations

4.2.3.1 Observed variation

Table 41 gives an overview of the variation of the exchangeable cation content of the humus layer on loess and peat soils. The data for Ca, Mg, K and Na are presented as the total base cation content. The contents of exchangeable H and Al are presented in separate columns. Table 42 gives an overview of the variation in the pools of exchangeable cations in the humus layer. For the forest locations without an humus layer (nine locations on peat soils, for which no concentrations were measured), the size of the pools of exchangeable cations as assumed to be 0.

The base saturation of the humus layer is almost equal for the loess soils and the peat soils (Table 41). The median exchangeable H content is about 20% for both peat and loess soils. The Al saturation of the CEC of the humus layer on loess and peat soils is low compared to the one in sandy soils: 6.3%. For peat soils this can be explained from the absence of a mineral soil below underneath humus layer, which is the main source of Al in the humus layer. At several locations on loess soils the base saturation of the humus layer is (more than) 100% and is thus the H or Al saturation 0%. Also for the peat soils some locations have exchangeable H and Al concentration of 0%. However, the maximum base saturation of the humus layer on peat soils is 'only' 87%. This lack can be explained by the share of NH_4, Fe and Mn on the CEC, which have maximum values of 14%, 5.2% and 5.0%, respectively. The median value of NH_4 in peat soils is 8.7%.

Table 41 Minimum, maximum, 5th, 50th and 95th percentiles of the exchangeable cation content (in percentage of the CEC) of the humus layer

Statistic [1]	H (%)		Al (%)		B.C. [2] (%)	
	Loess	Peat	Loess	Peat	Loess	Peat
Minimum	0.0	0.0	0.0	0.0	33	43
5th percentile	0.0	0.0	0.0	0.0	34	44
50th percentile	20	21	3.7	1.1	66	67
95th percentile	45	41	12	3.1	97	86
Maximum	50	42	13	4.1	98	87

[1] No data available for the clay soils, due to the almost absence of a humus layer on most locations.
[2] B.C. (base cations) = Ca + Mg + K + Na

The distribution over the different exchangeable base cations shows that Ca is the main base cation: median value 51% for loess soils and 43% for peat soils. The exchangeable Mg, K and Na contents are higher for peat soils than for loess soils. For both parent materials exchangeable Ca, Mg and Na contents are higher than for sandy soils, but exchangeable K contents are considerably lower.

Compared with the results for the sandy soils (De Vries & Leeters, 1999), the base saturation of the CEC in the humus layer of the loess soils and the peat soils is two times as high. Consequently, the H occupation and the Al occupation are lower for the loess soils and the peat soils. (The median values for the sandy soils are: 45% H, 6.5% Al and 37% base cations; cf. De Vries & Leeters, 1999).

In both loess and peat soils the base cations mainly account for the amount of exchangeable cations (cf. Table 36). However, these amount are smaller than for sandy soils: (median value 11 $kmol_c\ ha^{-1}$), which is due to the much thicker humus layers and the much larger CEC on sandy soils. The median exchangeable Ca pools are 5.8 and 5.5 $kmol_c\ ha^{-1}$, for loess and peat respectively. For Mg these numbers are 1.1 and 2.2 $kmol_c\ ha^{-1}$, respectively. The larger amount of humus on sandy soils also accounts for the even larger difference with the amounts of exchangeable H and Al on sandy soils (13 and 1.9 $kmol_c\ ha^{-1}$, respectively; cf. De Vries & Leeters, 1999). The median amount of exchangeable NH_4 in the humus layer on peat soils is 0.98 $kmol_c\ ha^{-1}$, with a maximum of 3.4 $kmol_c\ ha^{-1}$.

Table 42 Minimum, maximum, 5th, 50th and 95th percentiles of the exchangeable cation pools in the humus layer

Statistic [1]	H ($kmol_c\ ha^{-1}$)		Al ($kmol_c\ ha^{-1}$)		B.C [2] ($kmol_c\ ha^{-1}$)	
	Loess	Peat	Loess	Peat	Loess	Peat
Minimum	0.00	0.00	0.00	0.00	1.4	0.00
5th percentile	0.00	0.00	0.00	0.00	1.7	0.00
50th percentile	2.5	2.0	0.54	0.12	7.5	8.4
95th percentile	13	9.9	3.5	0.53	18	18
Maximum	16	10	5.6	0.58	20	30

[1] No data available for the clay soils, due to the almost absence of a humus layer on most locations.
[2] B.C. (base cations) = Ca + Mg + K + Na

4.2.3.2 Relations with the environmental characteristics

Tree species

Within the loess soils, the composition of the exchangeable cation contents of humus layer under 'other deciduous species' on loess soils contrasted strongly with the other tree species (Table 43). The median base saturation is almost 100% and median contents of H and Al of 0%. For the other tree species the median base saturation varies between 43 and 61%. The 'conifers' had the highest median contents of exchangeable H and Al and the lowest base saturation.

Within the peat soils, the differences in occupation of the CEC are relatively small. The H occupation is slightly lower for the plots with alder, whereas the base saturation is slightly higher (Table 43).

Table 43 Median values of the exchangeable cation content (in percentage of the CEC) of the humus layer as a function of the tree species [1].

Tree species [2]	H (%)	Al (%)	B.C. [3] (%)
Loess soils:			
Oak	24	4.2	61
Beech	25	4.0	55
Other deciduous	0.0	0.0	94
Conifers	37	6.9	43
Expl. variance (% R^2_{adj})	*24*	*30*	*34*
Peat soils:			
Birch	21	1.1	65
Birch + oak	21	1.1	67
Birch + alder	15	0.8	72
Expl. variance (% R^2_{adj})	*2*	*1*	*0*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.
[2] No data available for the clay soils, due to the almost absence of a humus layer on most locations.
[3] B.C. (base cations) = Ca + Mg + K + Na

Soil types

Within the loess soils, the median base saturation of the Fluvisols is (more than) 100% and median contents of H and Al of 0.0%. For the other clusters the median base saturation varies between 43 and 69%. The Cambisols in sandy loess have the lowest base saturation and the highest median exchangeable H and Al content (Table 44).

Table 44 Median values of the exchangeable cation content (in percentage of the CEC) of the humus layer as a function of the soil type [1].

Soil type [2]	H (%)	Al (%)	B.C. [3] (%)
Loess soils:			
Cambisol in sandy loess	38	5.7	43
Cambisol in loamy loess	15	3.1	68
Haplic and Gleyic Luvisol	19	3.9	69
Eutric and Calcic Fluvisol	0.0	0.0	97
Expl. variance (% R^2_{adj})	*37*	*31*	*35*
Peat soils:			
Fibric Histosol, high moor	29	1.2	56
Terric Histosol, high moor	21	1.2	67
Fibric Histosol, low moor	2.5	1.1	84
Expl. variance (% R^2_{adj})	*53*	*3*	*48*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.
[2] No data available for the clay soils, due to the almost absence of a humus layer on most locations.
[3] B.C. (base cations) = Ca + Mg + K + Na

Within the peat soils, there is a clear difference between the low moor locations and the high moor locations (Table 44). For the low moor location the median base saturation of the humus layer is 84%, with a median content of exchangeable H of only 2.5%. For the high moor soils the median base saturation of the humus layer is around 60% with median content of exchangeable H between 20 and 30%. The higher base saturation of the humus layers in the low moor area might be related to the weak influence of the nearby mesotrophic surface water, like mentioned earlier.

Statistical analysis

For the loess soils the H and Al occupation and the base saturation of the humus layer are clearly determined by the combination of soil type and tree species (Table 45; simple model), but also by relatively well by the separate factors (Tables 43 and 44). Extension of the statistical model with all other environmental characteristics results in the addition of the deposition level (of NH_x; positive) and the distance to the forest edge (negative) for the H and Al occupation. This is an analogous pattern as for pH(H_2O) and pH(KCl) (Table 36): a significant acidifying impact of atmospheric deposition combined with a possible neutralizing effect of base deposition at forest edges. No such pattern can be revealed for the base saturation, for which the predictor tree species remains in the model.

For the peat soils, the simple statistical model yields in only the soil type as a relevant explaining factor for the differences in the H occupation and base saturation of the humus layer (Table 45). In the full model, the soil type stays in the model for the H occupation and the base saturation. The H occupation is also negatively correlated with the distance to open water, indicating that nearby surface water may have a buffering impact. No good explanation could be found for the negative correlation of H occupation (only in the low moor area) and the Al occupation with the deposition level (of SO_x). However, the contribution of this deposition variable is only weakly significant.

Table 45 Best explaining environmental characteristics for the exchangeable cation content (in percentage of the CEC) of the humus layer, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	$\%R^2_{adj}$	Sign. [3]	Factors	$\%R^2_{adj}$	Sign. [3]
Loess soils:						
H	So + Tr	42	***	So + Dp_{nh} + Ds	58	***
Al	So + Tr	42	***	So + Dp_{nh} + Ds	51	***
B.C.	So + Tr	49	***	So + Tr	49	***
Peat soils:						
H	So	53	***	So + Ds_w + Dp_l.So	82	***
Al	So	13	-	Dp_{so}	16	*
B.C.	So	48	**	So	48	**

[1] Simple model: analysis only with 'Tree species' and 'Soil Type' (coding cf. Section 2.4).
[2] Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).
[3] Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

4.3 Heavy metals

4.3.1 Observed variation

Accumulation of heavy metals in forest ecosystems is one of the reasons for the decrease in vitality of forest stands. The main source of heavy metals in forest soils is the atmospheric deposition of heavy metals from emissions by industry and traffic, and possibly remnants of heavy metal containing fertilizers used in the past. Some forest might be planted on locations with heavy metal pollution caused by the former dumping of heavy metal containing waste. Because of their origin and their strong fixation to organic matter, the heavy metals mainly accumulate in the humus layer and the mineral topsoil (Kleyn et al., 1989; Groot & Van Swinderen, 1993). Tables 46 and 47 give an overview of the heavy metal contents of the humus layer and a comparison of these results with the present criteria in the Dutch environmental policy.

The heavy metal contents of the humus layer are slightly skew distributed over the locations on loess and peat soils (Table 46). The (median values of the) Pb, Cu, Ni and Cr contents are higher for the loess soils than for the peat soils. The Cd and Zn contents are higher for the peat soils.

The Pb and Ni contents of both loess and peat soils are considerably lower than for the sandy soils (De Vries & Leeters, 1999). The Cd and Zn content are higher than for the sandy soils. For the Cr contents, the results for the loess soils are higher than for the sandy soils, while those for the peat soils are lower. There is not much difference with the sandy soils for the Cu contents.

Table 46 Minimum, maximum, 5th, 50th and 95th percentiles of the heavy metal contents ($mg\ kg^{-1}$) in the humus layer

Statistic [1]	Pb	Cd	Cu	Zn	Ni	Cr
Loess soils:						
Minimum	21	0.28	10	41	4.9	8.7
5th percentile	23	0.34	12	58	5.3	17
50th percentile	99	0.80	18	134	9.8	31
95th percentile	222	2.5	27	289	16	51
Maximum	372	2.6	46	386	18	55
Peat soils:						
Minimum	23	0.52	6.9	64	2.8	2.7
5th percentile	23	0.55	7.6	82	3.1	3.0
50th percentile	62	1.0	14	211	5.3	7.7
95th percentile	115	2.3	30	435	8.9	15
Maximum	130	2.5	39	452	9.2	16

[1] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

There are only few exceedances of the lowest critical level (the 'Target Value', according to the Dutch legislation described in Section 2.4.3) for Cu and Cr (Table 47). For these elements most humus layers are 'clean' according to the Dutch legislation. However, this lowest critical level is exceeded many times for Zn, Pb and Cd. These are the heavy metals that mostly enter the forest ecosystem by atmospheric deposition. Relatively strong correlations between Zn and Cd are found for the loess and peat soils, analogous to correlation between Pb and Cd for the sandy soils (De Vries & Leeters, 1999).

Most locations with an exceedance of the 'Target Value' have heavy metal concentrations below the 'Examination Value', which means that these locations are slightly polluted, but not seriously. For one location on loess soils the 'Examination Value' for Pb is exceeded. For two locations on loess soils and six locations (out of 21) on peat soils, this value for Zn is exceeded. This (formally) means that a further investigation of the source and extent of the pollution is required. The 'Intervention Value' is exceeded at none of the locations.

Table 47 Distribution (in number of plots) of the heavy metal contents of the humus layer over the soil pollution classes for heavy metals, according to the Dutch criteria for soil pollution

Pollution class [1]	Pb	Cd	Cu	Zn	Ni	Cr
Loess soils:						
< Target Value	15	30	38	7	39	37
> Target Value	23	9	1	30	0	2
> Examination Value	1	0	0	2	0	0
> Intervention Value	0	0	0	0	0	0
Peat soils:						
< Target Value	16	11	20	1	21	21
> Target Value	5	10	1	14	0	0
> Examination Value	0	0	0	6	0	0
> Intervention Value	0	0	0	0	0	0

[1] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Table 48 Minimum, maximum, 5th, 50th and 95th percentiles of the heavy metal pools (kg ha^{-1}) in the humus layer

Statistic [1]	Pb	Cd	Cu	Zn	Ni	Cr
Loess soils:						
Minimum	0.06	0.00	0.04	0.74	0.02	0.06
5th percentile	0.09	0.00	0.05	0.83	0.03	0.07
50th percentile	4.6	0.03	0.76	4.8	0.41	1.2
95th percentile	21	0.08	3.2	19	1.9	6.6
Maximum	54	0.12	6.7	27	2.6	8.0
Peat soils:						
Minimum	0.00	0.00	0.00	0.00	0.00	0.00
5th percentile	0.00	0.00	0.00	0.00	0.00	0.00
50th percentile	1.7	0.03	0.42	3.0	0.17	0.20
95th percentile	7.8	0.13	1.3	26	0.44	0.77
Maximum	7.8	0.14	1.4	30	0.55	0.81

[1] No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Table 48 gives an overview of the variation in the pools of heavy metals in the humus layer. The pools of heavy metals in the humus layer origin almost completely from the deposition of heavy metals, since they are strongly bound to the organic matter in the humus layer. Especially in locations with a humus layer of a considerable thickness, the pools of heavy metals are important indicators for the rate of heavy metal deposition, since the binding capacity of these layers is large enough to absorb the heavy metal deposition of many years. For the forest locations without an humus layer (nine locations on peat soils, for which no concentrations were measured), the size of the heavy metal pools was assumed to be 0.

4.3.2 Relations with the environmental characteristics

Tree species

Within the loess soils, the highest Cd and Zn contents and the lowest Pb, Cu and Ni contents of the humus layer occur in coniferous stands (Table 49). The highest Cu, Ni and Cr contents occur in beech stands. The highest Pb contents occur in 'other deciduous' stands (poplar etc.).

Within the peat soils, little variation is found in the heavy metal contents of the humus layer as a results of the distribution over the tree species (Table 49). The pure birch cluster had the highest Cd contents and the lowest Mn contents. The cluster with oak had the lowest Zn contents. The cluster with alder had lowest Cr contents.

Table 49 Median values of the heavy metal contents (mg kg^{-1}) in the humus layer as a function of the tree species.

Tree species [2)]	Pb	Cd	Cu	Zn	Ni	Cr
<u>*Loess soils:*</u>						
Oak	102	0.67	17	120	9.7	31
Beech	115	0.67	22	134	11	41
Other deciduous	133	0.84	18	132	10	28
Conifers	44	1.95	13	184	7.8	29
Expl. variance (% R^2adj)	*18*	*28*	*8*	*8*	*9*	*1*
<u>*Peat soils:*</u>						
Birch	57	1.6	14	269	5.3	7.7
Birch + oak	63	0.99	13	180	5.4	7.6
Birch + alder	59	1.1	13	261	5.2	5.7
Expl. variance (% R^2adj)	*0*	*3*	*0*	*7*	*0*	*0*

1) Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

2) No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Soil types

Within the loess soils, the highest Cu, Ni and Cr contents of the humus layer occur on the Luvisols (Table 50). The highest Cd and Zn contents (and the lowest Pb and Cu contents) occur on the Fluvisols. The highest Pb contents (and the lowest Cd and Zn contents) occur on the Cambisols in sandy loess. Except for the Cr content this cluster is very similar to the sandy soils (cf. De Vries & Leeters, 1999).

Within the peat soils, the lowest contents of all seven heavy metals occur in the low moor area. Within the high moor area the highest Pb, Zn and Ni contents occur on the Fibric Histosols. The highest Cd and Mn contents occur on the Terric Histosols.

Table 50 Median values of the heavy metal contents (mg kg^{-1}) in the humus layer as a function of the soil type [1].

Soil type [2]	Pb	Cd	Cu	Zn	Ni	Cr
Loess soils:						
Cambisol in sandy loess	133	0.43	16	62	9.8	29
Cambisol in loamy loess	99	0.80	19	149	9.8	32
Haplic and Gley. Luvisol	115	0.84	20	160	11	34
Eutr. and Calc. Fluvisols	40	2.0	13	213	8.8	27
Expl. variance (% R^2adj)	*14*	*30*	*7*	*35*	*1*	*0*
Peat soils:						
Fibr. Histosol, high moor	75	1.0	14	248	5.8	8.1
Terr. Histosol, high moor	62	1.6	14	234	5.3	8.2
Fibric Histosol, low moor	40	0.81	12	141	4.8	4.2
Expl. variance (% R^2adj)	*10*	*10*	*2*	*0*	*0*	*15*

1) Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

2) No data available for the clay soils, due to the almost absence of a humus layer on most locations.

Statistical analysis

For the loess soils, only the Cd and Zn contents of the humus layer show a significant correlation with the combination of the soil type (and the tree species) (Table 51). Weakly significant correlations were found for the Cu, Zn and Cr contents. The extension of the model with all other environmental factors, results in the addition of the deposition level (mostly of SO_x) for the Pb, Cd, Cu, Zn and Ni contents. Although the deposition of S or N compounds has no direct relationship with the contents of heavy metals in the humus layer, there might be a correlation between the deposition of acidity or N compounds and the deposition of these heavy metals, within the loess region. The negative correlation with the distance to the forest edge and some of these metals indicates that the dry deposition of these metals may also play a role.

For the peat soils, there are hardly any significant correlation with the environmental characteristics found for the heavy metal contents in the humus layer (Table 51). The soil type explains only a small, non-significant percentage of the variance of most elements, except for Cr for which soil type explains 30%. The only element for which a significant improvement is achieved after extension of the model with all other environmental characteristics was Zn, for which the variation is explained well by the combination of soil type, drainage class and neighbouring land use type. The highest Zn content were found on Terric Histosols, under Birch with alder and near maize lands.

Table 51 Best explaining environmental characteristics for the heavy metal contents in the humus layer, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	$\%R^2_{adj}$	Sign.[3]	Factors	$\%R^2_{adj}$	Sign.[3]
Loess soils:						
Pb	So + Tr	23	*	Tr + Dp_{so} + Hc	37	***
Cd	So + Tr	41	***	So + Tr + Ds + Dp_n	61	***
Cu	So + Tr	15	*	Dp_{so}	20	***
Zn	So	35	***	So + Ds + Dp_{so}.So	67	***
Ni	So + Tr	15	*	So + Dp_{no}	25	***
Cr	Tr	1	-	-	0	-
Peat soils:						
Pb	So	10	-	So	10	-
Cd	So + Tr	22	*	So + Tr	22	*
Cu	So	2	-	Dr_c	15	*
Zn	So + Tr	20	-	So + Dr + La	65	**
Ni	-	0	-	-	0	-
Cr	So	30	*	So	30	*

1) Simple model: analysis only with 'Tree species' and 'Soil Type' (coding cf. Section 2.4).
2) Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).
3) Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

4.4 Summary and conclusions

The following summarizing conclusions can be drawn from the preceding sections:

1. The **thickness** of the humus layer decreases from sandy soils > loess soils > peat soils > clay soils. On most clay soils hardly any humus layer was observed, due to the rapid decomposition on these rich soils covered with a poplar stand. Within the loess soils, the greatest thickness and the largest pools are observed for the Cambisols in sandy loess and for the beech. Within the peat soils they were found for the high moor soils. The differences in thickness of the humus layer are the most determining factor in the differences in the pools of nutrients, CEC and exchangeable cations.

2. With median values of 2.5% in the organic matter, the **N contents** in the humus layer of loess and peat soils was slightly higher than for the sandy soils. Within the loess soils, the highest N contents were found for the Luvisols and for the Conifers. Within the peat soils the highest N contents were found for the high moor soils.

3. The **contents of P, Ca, Mg and K** generally increases from peat soils < (sandy soils) < loess soils. Also within the loess and peat soils the contents of these elements show an increase from the more vulnerable soil types to the less vulnerable soil types.

4. The **pH** values for most loess and peat soils are comparable. The median values for the $pH(H_2O)$ and the pH(KCl) are 4.3 and 3.5, which is approximately 0.5 unit higher than for the sandy soils. The highest values for the loess soils, however, are much higher, with a maximum pH(KCl) value of 6.6. These high pH values are concentrated in the Fluvisols and under 'Other Deciduous Species'.

5. The **CEC** (of the organic matter) decreases from loess soils > sandy soils > peat soils. Within the loess soils, the highest CEC values were found for the Fluvisols and for the 'Other Deciduous Species', whereas the lowest values were found for the 'Sandy Loess Cambisols' and for the 'Beech'. Within the peat soils, the highest CEC values were found for the 'Low Moor Soils'. These difference can partly be explained by the influence of the pH on the CEC.

6. The **base saturation** for the loess and peat soils was with median values of 66% and 67%, respectively, two times as high as for the sandy soils. Consequently, the **H and Al occupation** were approximately half of the values for the sandy soils, with median values of 20% and 21% for the H occupation and of 3.7% and 1.1%, for the Al occupation. Within the loess soils, the highest base saturation was found for the 'Fluvisols' and for the 'Other deciduous species', whereas the lowest values were found for the 'Conifers' and for the 'Sandy loess Cambisols'. Within the peat soils, the highest base saturation was found for the 'Low moor soils'.

7. The **heavy metal contents** decreases from sandy soils > loess soils > peat soils for Pb, Cu and Ni, and increases in this order for Zn and Cd. The contents of Pb, Zn and Cd (which mainly originate from atmospheric deposition) exceeds mostly the so-called Target Values. For eight locations (six for loess and two for peat), the Zn contents even exceeds the 'Examination Value'. Within the loess soils, the highest contents of Zn and Cd (and most exceedances of critical levels) were found for the 'Conifers' and for the 'Fluvisols', whereas the highest Pb contents were found for the 'Other Deciduous Species' and for the 'Sandy Loess Cambisols'. Within the peat soils, the highest values for all six heavy metal contents (and most exceedances of critical values) were found for the 'High Moor Soils'

5 Chemical composition of the mineral soil

In this chapter we give an overview of the characteristics of the mineral soils, subdivided in contents and pools of organic matter (also bulk densities) and nutrients (Section 5.1), exchangeable cations (including pH; Section 5.2), oxalate extractable Al, Fe and P (Section 5.3) and total contents of the major minerals and heavy metals (Section 5.4). First the variation in the observed data is given and then the influence of soil type and soil layer is discussed.

5.1 Total contents of organic matter and nutrients

5.1.1 Organic matter and bulk density

5.1.1.1 Observed variation

Table 52 gives an overview of the contents and pools of organic matter and the bulk density of the mineral soil of loess, clay and peat soils. The figures for the organic matter contents and the bulk density have been calculated from all separate values, whereas the pools have been calculated per location, i.e. the values for the corresponding layers from one location have been lumped. The figures for the bulk density are estimates based on the pedo-transfer functions given in Table 2.

In the comparison of loess, clay and peat soils, the organic matter content is lowest for the loess soils, with a median value of 30 g kg^{-1} (Table 52). The minimum and median values for clay soils are twice as high. However, these relatively high values could hardly be observed (visually) in the field, because of the very intensive mixing of the humus with the mineral soil parts. The maximum values of 16% for both loess and clay soils are relatively high. The organic matter content of the peat soil has a very wide range. The minimum value of 14% indicates that there are samples that can not be classified as peat. However, most peat samples have an organic matter content that is typical for peat soils, with a median value of 93% and a maximum of almost 100%. Comparison with the results on the sandy soils (De Vries & Leeters, 1999) shows that only the results for the loess soils are comparable with those for the topsoil (0-30 cm) of the sandy soils, which have a median value of 3.8%. The results for the clay and peat soils are (much) higher.

The highest bulk densities (Table 52) are found in the loess soils and the lowest ones in the peat soils. The range of bulk densities for the loess soils is remarkably narrow. This indicates that most loess soils are rather compact. The bulk densities of the peat soils are very low, due to the very high organic matter content and the very loose structure. Comparison with the results on the sandy soils (De Vries & Leeters, 1999) shows that the median value found for the sandy topsoils (0-30 cm) is slightly higher than the corresponding value found here for the clay soils.

The pools of organic matter are smallest for loess soils (Table 52: median value 46 ton ha^{-1} dm^{-1}), followed by the clay soils, like found for the organic matter contents. The median amount of organic matter in the peat soils is approximately 150 ton ha^{-1} dm^{-1}.

Table 52 Minimum, maximum, 5th, 50th and 95th percentiles of the organic matter content, the bulk density and the total pools of organic matter in the mineral soil

Statistic	Org. matter content (g kg^{-1})			Bulk density (kg m^{-3})			Org.Matter pool (ton ha^{-1} dm^{-1})		
	Loess	Clay	Peat	Loess	Clay	Peat	Loess	Clay	Peat
Minimum	1.5	10	143	1 109	948	152	25	31	94
5th percentile	4.3	14	468	1 411	1 134	154	26	32	103
50th percentile	19	36	930	1 538	1 293	163	46	56	150
95th percentile	110	118	985	1 557	1 505	264	108	103	152
Maximum	180	189	997	1 618	1 589	437	129	190	152

5.1.1.2 Differences between the soil layers

For the loess and clay soils, there was a clear and very significant decrease in the organic matter content of the loess soils with the depth (Table 53). The median value decreases from 8.7 to 0.6%. for the loess soils and from 7.8% to 2.1% for the clay soils. However, the decrease is not very regular: there is a steep drop from the first to the second layer. Some of the observed clay soil profiles clearly show the presence of one (or even more) buried Ah horizons.

The general pattern of the organic matter contents of the peat soils shows a slight increase with depth until 60 cm, but this trend is not significant (Table 53). Table 47, however, does not show the different patterns for the three soil types. For the Terric Histosols the organic matter contents of the first layer is considerably lower than average (median value: 794 g kg^{-1} vs. approximately 950 g kg^{-1} for the other layers), whereas for the Low Moor soils the middle two layers have considerable lower organic matter contents than average (around 700 g kg^{-1}).

The bulk densities for loess soils show an increase with depth, but the deepest two layers have the same value (Table 53). The highest bulk density for the clay soils is found in the second layer with a strong decrease to the first and a slight decrease to the third and fourth layer. The lower values of the topsoil are due to the high organic matter contents, whereas the decrease lower in the soil profile is related to an increase of the clay contents. The bulk densities for the peat soils are almost equal for the soil layers and do, therefore, not show a significant trend.

The variation with depth for the pools of organic matter is mainly correlated with the pattern in the organic matter content and partly also with the variation in bulk density. These two factors seem to compensate each other completely in most of the peat soils (Table 53), although there were also plots with a clear trend. Like for the results for the organic matter contents, the pools of organic matter were higher in the clays soils than in the loess soils, except for the top 10 cm.

Table 53 Median values (per soil layer) of the organic matter content, bulk density and the total amount of organic matter in the mineral soil

Soil layer	Organic matter content (g kg^{-1})	Bulk density (kg m^{-3})	Organic Matter pool (ton ha^{-1} dm^{-1})
Loess soils:			
0 - 10 cm	87	1 420	124
10 - 30 cm	27	1 520	41
30 - 60 cm	11	1 553	17
60 - 100 cm	5.9	1 553	9
Expl. variance (% R^2_{adj})	*90*	*49*	*89*
Clay soils:			
0 - 10 cm	78	1 222	96
10 - 30 cm	44	1 322	56
30 - 60 cm	27	1 306	35
60 - 100 cm	21	1 290	29
Expl. variance (% R^2_{adj})	*76*	*27*	*74*
Peat soils			
0 - 10 cm	921	164	151
10 - 30 cm	933	163	151
30 - 60 cm	950	160	151
60 - 100 cm	930	163	151
Expl. variance (% R^2_{adj})	*2*	*0*	*0*

5.1.1.3 Relations with the environmental characteristics

Soil types

Within the loess soils, the lowest organic matter contents (and pools) are found in the sandy loess Cambisols (Table 54). The highest organic matter contents are found in the Fluvisols, which have a similar result as the medium-textured Fluvisols in the clay area. The lowest bulk density is found for the Luvisols. There are only slight differences in bulk density among the other soil types. Within the clay soils, the fine-textured Fluvisols have the highest organic matter content. The bulk density for the fine textured clay soils is lower than for the median textured clay soils, due to the higher clay contents and higher organic matter contents. The pools of organic matter for loess and clay soils show the same sequence as the contents in percentages.

Within the peat soils, the Histosols in the low moor area have considerably lower organic matter contents and organic matter pools than the two types in the high moor area (Table 54). The highest values for the bulk density are also found for the locations in the low moor area, due to the higher content of mineral particles. The differences between the two high moor soil types are relatively small.

Table 54 Median values of the organic matter content, the bulk density and the pools (in the top 100 cm) of organic matter in the mineral soil as a function of the soil type [1].

Soil type	Organic matter content ($g\ kg^{-1}$)	Bulk density ($kg\ m^{-3}$)	Organic Matter pool ($ton\ ha^{-1}\ dm^{-1}$)
Loess soils:			
Cambisol in sandy loess	13	1 549	46
Cambisol in loamy loess	19	1 553	47
Haplic and Gleyic Luvisol	16	1 429	44
Eutric and Calcic Fluvisol	34	1 551	48
Expl. variance (% R^2adj)	*3*	*35*	*3*
Clay soils:			
Eutr. Fluvisol, med. texture	36	1 412	51
Eutr. Fluvisol, fine texture	34	1 276	57
Calc. Fluvisol, fine texture	38	1 304	53
Expl. variance (% R^2adj)	*0*	*29*	*0*
Peat soils:			
Fibric Histosol, high moor	959	158	152
Terric Histosol, high moor	931	163	150
Fibric Histosol, low moor	759	192	147
Expl. variance (% R^2adj)	*40*	*21*	*7*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

Statistical analysis

For the loess and clay soils, the simple model does not offer a satisfactory explanations of the variation in the observed variation in the contents and pools of organic matter (Table 55). The bulk density of these soils, on the contrary is strongly correlated with the soil type, and for the clay soils also with the drainage class. For the clay soils, the contents and pools of organic matter decrease with increasing drainage, both in the simple and in the complete model.

After extension of th available set of predictors with all other environmental characteristics, the bulk density of the loess soils seems also correlated with the deposition level (of SO_x). This is probably an artefact. The same is probably the case for the inclusion of the canopy closure for the contents and pools of organic matter for both the loess and clay soils and the direction to the forest edge for the clay soils.

The organic matter content in the clay soils is strongly correlated with the soil type, with the lowest values for the low moor area (Tables 54 and 55). Besides, the organic matter contents seems to increase with increasing drainage. The contribution of this relationship, which is opposite as expected, is only marginal. The bulk density of the peat soils shows a weakly significant relationship with the soil type. This relationship, however, is closely related to (the inverse of) the organic matter contents. This effect completely eliminates the existence of any relationships for the organic matter pools.

Table 55 Best explaining environmental characteristics for the organic matter content, bulk density and the total amount of organic matter in the mineral soil, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	$\%R^2_{adj}$	Sign.[3]	Factors	$\%R^2_{adj}$	Sign.[3]
Loess soils:						
Org.Matter content	So + Dr	9	-	Dr + Ca + Dp_{no}.Dr	41	***
Bulk density	So	35	***	So + Dp_{so}.So	58	***
Org.Matter pool	So + Dr	11	*	Dr + Ca + Dp_{nb}.Dr + Di	44	**
Clay soils:						
Org.Matter content	Dr_c	16	-	Dr_c + Di + Ca	44	***
Bulk density	So + Dr	56	***	So + Dr	56	***
Org.Matter pool	Dr_c	14	*	Dr_c + Ca + Di	41	***
Peat soils:						
Org.Matter content	So + Dr_c	44	***	So + Dr_c	44	***
Bulk density	So + Dr	23	*	So	21	*
Org.Matter pool	So	7	-	So + La	63	***

[1] Simple model: analysis only with 'Soil Type' and 'Drainage Class (coding cf. Section 2.4).
[2] Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).
[3] Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

5.1.2 Organic carbon, nitrogen and phosphorus

5.1.2.1 Observed variation

Table 56 gives an overview of the variation in C, N and P contents of the mineral soil. For loess soils, the C contents have only been determined for the layers 0-10 cm and 10-30 cm. The contents are expressed in percentages of the organic matter. Besides the following ratios haven been calculated: C/N, C/P and N/P (Table 57). The N and P contents have been used for the calculation of the pools of total N and total P (Table 58).

The organic matter in clay soils has very low C contents, with a median value of only 29% (Table 56). The highest C contents (of the organic matter) are found for the peat soils. However, the maximum values for the C content of the three parent materials are relatively close to each other. The highest (median) N contents are found for the clay soils. The values for loess soils are slightly lower. The lowest N contents are found for the peat soils, although at the top end of the range some peat samples with very high N contents are found. P contents, expressed in a percentage of organic matter are much higher for mineral soils (loess and clay) than for peat soils. The main reason is that, unlike C and N, P is only partly bound in organic matter. A larger fraction of P is bound in minerals or is absorbed to Al/Fe compound (Section 5.1.3). P contents per kg soil are more comparable for loess, clay and peat soils, with median values of 0.30, 0.67, 0.38 g kg^{-1}, respectively.

The C and N contents of the organic matter for the loess soils compare well with those found for the sandy topsoils (0-30 cm) (median values 43%. and 2.0%; cf. De

Vries & Leeters, 1999). The P contents of the loess and clay soils is much higher than the P contents of the sandy topsoils (0-30 cm), (median value 0.28; cf. De Vries & Leeters, 1999), but the values found for the peat soils are substantially lower.

Table 56 Minimum, maximum, 5th, 50th and 95th percentiles of C, N and P contents (in percentage of the organic matter) of the mineral soil

Statistic	C content (%)			N content (%)			P content (%)		
	Loess [1]	Clay	Peat	Loess	Clay	Peat	Loess	Clay	Peat
Minimum	37	37	36	0.93	1.5	0.87	0.15	0.45	0.01
5th percentile	42	42	42	2.0	3.3	0.98	0.30	0.74	0.02
50th percentile	49	46	49	3.7	4.8	1.6	1.5	1.7	0.05
95th percentile	56	57	53	4.7	6.1	3.7	6.7	5.3	0.23
Maximum	65	63	67	5.7	7.2	4.2	55	12	0.57

[1] Numbers for C content of loess soils based on layers 0-10 and 10-30 cm only.

The lowest C/N and C/P ratios are found in the clay soils with median values 9.8 and 28, respectively (Table 57). The values for these ratios for the loess soils are about two times as high. The N/P ratios have approximately the same range for loess as for peat soils. The C/N ratios for the peat soils are relatively high and the C/P and N/P ratios are extremely high. This indicates that the peat soils are rather poor in relative N content and extremely poor in relative P content. On the contrary, the results for the clay soils indicate a favourable humus type and good conditions for the nutrition of plants.

The C/N ratios of the loess soils are slightly lower than those found for the sandy topsoils (0-30 cm) (median value 20; De Vries & Leeters, 1999). The C/P and N/P ratios for loess and clay soils are considerably lower than those found for the sandy topsoils (median values 154 and 7.6, respectively; De Vries & Leeters, 1999), but the values for the peat soils are still much higher. However, the P ratios may be influenced by a big share of non-organic P.

Table 57 Minimum, maximum, 5th, 50th and 95th percentiles of nutrient ratios of C, N and P contents of the mineral soil

Statistic	C/N ratio (kg kg^{-1})			C/P ratio (kg kg^{-1})			N/P ratio (kg kg^{-1})		
	Loess [1]	Clay	Peat	Loess [1]	Clay	Peat	Loess	Clay	Peat
Minimum	10	7.1	11	20	5.4	104	0.02	0.62	6.6
5th percentile	12	8.1	13	25	9.9	203	0.64	0.91	12
50th percentile	17	9.8	28	65	28	1 068	2.4	2.8	38
95th percentile	27	14	52	218	60	2 534	7.4	5.3	63
Maximum	31	33	61	371	110	5 321	12	7.3	112

[1] Numbers for C ratios of loess soils based on layers 0-10 and 10-30 cm only.

The smallest values for the pool of N are found for the loess soils (Table 58). These values are still considerable higher than generally found in the sandy soils (De Vries & Leeters, 1999). The values for the clay soils are slightly higher than those for the peat soils. The large amounts of organic matter in the peat soils make that the amounts of N are almost as large as those for clay soils, despite the low contents in percentage of the organic matter contents. This result shows that peat soils can absorb large amounts of N (from atmospheric deposition) and still have high C/N ratios. The smallest amounts of nitrogen are found in the loess soils. The highest amounts of P are found in the clay soils, which is almost two times as much as found in the loess soils. The amount of P is smallest by far in the peat soils, which shows values that are even considerably lower than found in the sandy soils (De Vries & Leeters, 1999).

Table 58 Minimum, maximum, 5th, 50th and 95th percentiles of the total pools of N and P in the top 100 cm of the mineral soil

Statistic	C pool (ton ha^{-1} dm^{-1})			N pool (ton ha^{-1} dm^{-1})			P pool (ton ha^{-1} dm^{-1})		
	Loess [1]	Clay	Peat	Loess	Clay	Peat	Loess	Clay	Peat
Minimum	16	14	47	0.50	1.1	1.7	0.14	0.44	0.03
5th percentile	21	15	55	0.68	1.6	1.8	0.16	0.63	0.03
50th percentile	38	26	72	1.4	2.7	2.2	0.49	0.84	0.09
95th percentile	74	45	78	3.3	4.0	5.2	1.1	1.9	0.28
Maximum	110	93	78	4.7	4.1	5.5	1.5	2.8	0.40

[1] Numbers for the C pools of the loess soils for the layer 0-30 cm only, instead of 0-100 cm.

5.1.2.2 Differences between the soil layers

The C content doe not show a significant pattern with the depth for all three parent materials (Tables 59). The N and P contents increase with the depth for the loess and clay soil, except for the fourth layer of the clay soils. On the contrary, the peat soils show an decrease of the N and P contents with depth until 60 cm.

Table 59 Median values (per soil layer) of the C, N and P contents (in percentage of the organic matter) and their ratios in the mineral soil

Soil layer	Nutr. content (% of O.M.)			Nutr. ratio (kg kg^{-1})			Nutr. pool (ton ha^{-1} dm^{-1})		
	C	N	P	C/N	C/P	N/P	C	N	P
Loess soils:									
0 - 10 cm	48	2.6	0.50	19	91	4.9	57	3.1	0.58
10 - 30 cm	50	3.1	1.2	16	43	2.9	20	1.2	0.41
30 - 60 cm	-	4.0	2.4	-	-	1.7	-	0.68	0.45
60 - 100 cm	-	4.1	4.3	-	-	0.92	-	0.37	0.43
Expl. var. (% R^2adj)	*17*	*54*	*82*	*43*	*80*	*74*	*90*	*87*	*16*
Clay soils:									
0 - 10 cm	45	4.3	1.0	9.7	26	2.7	45	4.2	1.0
10 - 30 cm	46	4.8	1.5	9.4	29	2.9	26	2.8	0.86
30 - 60 cm	48	5.5	2.1	9.8	26	2.7	16	1.8	0.68
60 - 100 cm	47	4.9	2.6	10.0	30	3.0	14	1.3	0.74
Expl. var. (% R^2adj)	*10*	*26*	*63*	*17*	*63*	*61*	*75*	*78*	*36*
Peat soils:									
0 - 10 cm	48	2.0	0.06	24	723	31	71	2.9	0.09
10 - 30 cm	49	1.5	0.04	34	1 105	37	70	2.2	0.06
30 - 60 cm	49	1.3	0.02	40	2 043	48	72	1.9	0.04
60 - 100 cm	49	1.3	0.02	36	2 051	53	73	2.0	0.03
Expl. var. (% R^2adj)	*4*	*23*	*43*	*28*	*46*	*47*	*2*	*19*	*44*

For the loess soils, the N/P ratio decreases significantly with depth, whereas it increases with depth for the clay and peat soils. For the clay soils, the C/N and C/P ratios increase significantly with depth. The levels, however, remain relatively low. For the peat soils, the C/N and C/P ratios show a strong and significant increase with depth until 60 cm. These patterns indicate, that for the peat soils a considerable enrichment with nutrients is going on from the top of the soil profile.

5.1.2.3 Relations with the environmental characteristics

Soil types

Within the loess soils, the N contents of the organic matter and the N and P pools increase in the same order as the presented soil type, whereas the C/N and C/P ratios decrease (Table 60). The contents and pools of C do not show a consistent pattern. The Luvisol have the highest P contents and the lowest N/P ratio. The trend is, however, not reflected in the P pools.

Within the clay soils, the highest contents and the largest pools of N occur in the fine textured soils (Table 60). These soils also have the lowest C/N ratios and the highest N/P ratios. The same soil type has the lowest contents and the smallest pools of P and the highest C/P ratios.

Table 60 Median values of the C, N and P contents (in percentage of the organic matter) and their ratios in the mineral soil as a function of the soil type [1].

Soil type	Nutr. content (%)			Nutr. ratio ($kg\ kg^{-1}$)			Nutr. pool ($ton\ ha^{-1}$)		
	C [2]	N	P	C/N [2]	C/P [2]	N/P	C [3]	N	P
Loess soils:									
Cambisol, sandy l.	46	2.8	1.3	20	90	2.6	97	8.1	3.0
Cambisol, loamy l.	48	3.6	1.4	17	68	2.6	103	9.2	4.3
Haplic, Gl. Luvisol	51	3.8	1.8	17	55	2.3	93	9.3	5.2
Eutric, Ca. Fluvisol	49	4.0	1.5	13	50	2.8	101	14	5.9
Expl. var. (% R^2adj)	*15*	*24*	*4*	*13*	*0*	*0*	*3*	*14*	*1*
Clay soils:									
Eut. Fluvisol, med.-t.	47	4.1	2.0	12	24	2.0	176	18	11
Eut. Fluvisol, fine-t.	46	4.8	1.6	9.7	29	3.0	206	23	7.5
Calcaric Fluvisol	47	4.9	2.1	9.6	23	2.5	222	21	8.1
Expl. var. (% R^2adj)	*0*	*22*	*0*	*24*	*0*	*7*	*0*	*0*	*0*
Peat soils:									
Fib. Histosol, high m.	49	1.2	0.02	38	1 968	49	743	18	0.36
Ter. Histosol, high m.	49	1.4	0.03	35	1 535	40	740	20	0.59
Fib. Histosol, low m.	48	2.6	0.09	19	552	29	675	38	1.1
Expl. var. (% R^2adj)	*0*	*52*	*35*	*50*	*35*	*17*	*4*	*52*	*37*

1) Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.
2) Numbers for C contents and C ratios of loess soils based on layers 0-10 and 10-30 cm only.
3) Numbers for the C pools of the loess soils for the layer 0-30 cm only, instead of 0-100 cm.

Within the peat soils, the contents and pools of N and P increase in the presented order of the soil types, whereas the three ratios all decrease in this order (Table 60). The sharpest contrasts occur between the high moor soil types and the low moor soils. The C contents of the three soil types are comparable, but the C pools decrease. These patterns indicate that the fibric histosols in the high moor area are the most oligotrophous soil type. Compared to the other soil types, P is stronger limited that N (all three ratios increase, including the N/P ratio).

Statistical analysis
The simple statistical model revealed hardly any significant relationships for the nutrient variable in the loess soils (Table 61). The only clearly significant relationship was found for the N contents with the soil type. Extension of the model with all other environmental characteristics gives the impression that the N contents (and also the P content) is correlated with the deposition of NO_x. This correlation, however, has a negative sign, which is opposite as could be expected. The same problem occurs with the correlations with the deposition levels for the C/N (and C/P) ratio and the P pools. Relatively good explainable are the relationships with the soil type and the drainage class. This also counts for the correlation between the N pools and the tree species. This all leads to the conclusion that the variation in the nutrient contents of the loess soils is predominantly related to natural variations, such as indicated by soil type, drainage class and tree species.

The only significant relationship found for the clay soils within the simple model was found for the N pools, which show a decrease with increasing drought (Table 61). Less significant relationships were found for the N content and C/N ratio, which both pointed at a better N supply under wetter conditions. Soil type seems to be dominant, however, for the explanation of the variation in C/N ration and N content. The extension of the statistical model for the clay soils with all other environmental characteristics, reveals the correlation with various stand characteristics, such as canopy closure and distance to the forest edge. Most of these relationships, however, can only be considered as artefacts, due to the limited number of plots. If any relationship could be substantiated, especially for the P variables, it could well be the case that the observed tree height etc. is a effect of the soil chemical condition rather than a cause.

The variation in the contents and pools of N and in the C/N ratio in the peat soils is explained well by the combination of the soil type and the drainage class (Table 61). The C/N ratio increases and the contents and pools decreases with increasing drought. The variation in the P variables is, in general, correlated with the soil type. Most of the considered variables are, when analysing the extended model, also correlated with the NO_x deposition. The relationships were as expected (unlike the clay soils). This indicates that N deposition may play an important role in the variation in the N enrichment of oligotrophous peat soils.

Table 61 Best explaining environmental characteristics for the C, N and P contents (in percentage of the organic matter) and their ratios in the mineral soil, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	$\%R^2_{adj}$	Sign.[3]	Factors	$\%R^2_{adj}$	Sign.[3]
Loess soils:						
C content	So + Dr	16	*	So + Ds	27	**
N content	So	24	**	Tr + Dp_{no} + He	60	***
P content	Dr	4	-	Dr + Dp_{no}	11	***
C/N ratio	So + Dr	20	*	So + Dr + Dp_t + Tr	57	***
C/P ratio	So + Dr	11	*	Dr + Dp_{no} + Di	31	**
N/P ratio	Dr	6	*	Dr + Ca	15	*
C pool	So + Dr	22	*	Dr + Di	28	***
N pool	So + Dr	16	*	Tr + Ca	44	***
P pool	So	1	-	Dp_t	15	**
Clay soils:						
C content	-	0	-	Di	31	***
N content	So + Dr_c	24	*	So + Ca + Ds	47	***
P content	Dr_c	4	-	Dr_c	4	-
C/N ratio	So + Dr_c	27	*	So + Dr_c + Ca + Dp_{no}.So + Dp_{no}.Dr_c	73	***
C/P ratio	Dr_c	4	-	Dr_c + Ca	17	*
N/P ratio	So + Dr_c	18	*	He + Tr	52	***
C pool	Dr_c	14	*	Dr_c + Ca + Di	40	**
N pool	Dr_c	42	***	Dr_c + Di + Ca	55	***
P pool	So	0.2	-	He	18	*
Peat soils:						
C content	-	0	-	-	0	-
N content	So + Dr_c	62	***	So + Dr_c + Dp_{no}	72	***
P content	So + Dr_c	41	**	So + Dr_c+ Dp_{no}	55	***
C/N ratio	So + Dr_c	59	***	So + Dr_c + Dp_{no}	70	***
C/P ratio	So + Dr_c	40	***	So + Dr_c+ Dp_{no}	55	***
N/P ratio	So	17	*	So	17	*
C pool	So	4	-	-	0	-
N pool	So + Dr_c	62	***	So + Dr_c + Dp_{no}	75	***
P pool	So + Dr_c	41	***	So + Dr_c + Dp_{no}	58	***

[1] Simple model: analysis only with 'Soil Type' and 'Drainage Class (coding cf. Section 2.4).
[2] Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).
[3] Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

5.2 pH and cation exchange characteristics

5.2.1 pH(H_2O) and pH(KCl)

5.2.1.1 Observed variation

The pH(H_2O) and pH(KCl) values show a very wide range for the loess and clay soils (Table 62). The maximum values for both parent materials indicate that in some samples the carbonate buffer is still active. The median values indicate, that, in general, most clay soils are in the upper (i.e. beginning) end of the cation exchange buffer range. Most loess soils are in the lower (i.e. further) part of this range. The minimum values for these two parent materials indicate, however, that in another part of the samples the Al buffer or even the Fe buffer is active in buffering the acid input. Most peat soils are very acid, with a median value of 3.7 for the pH(H_2O) and 2.9 for the pH(KCl), although there are some peat samples with a more moderate pH resulting in a maximum pH(KCl) of 5.4. The low minimum values for the pH shows that hardly any buffering is left in some other peat samples, resulting in a minimum pH(KCl) of 2.2.

The lower and middle range (minimum - median) of the pH(H_2O) and the pH(KCl) for the loess soils is in the same range as for the sandy soils (De Vries & Leeters, 1999). However, the upper end of the range of these parameters for the loess soils is much higher. The values for the pH(H_2O) and the pH(KCl) for the clay soils are considerably higher than for sandy soils. The values for the peat soils are considerably lower, except for the upper end of the range.

Table 62 Minimum, maximum, 5th, 50th and 95th percentile of the pH(H_2O) and the pH(KCl) in the mineral soil

Statistic	pH(H_2O)			pH(KCl)		
	Loess	Clay	Peat	Loess	Clay	Peat
Minimum	3.6	4.0	3.2	2.9	3.3	2.2
5th percentile	3.9	4.6	3.3	3.2	3.5	2.4
50th percentile	4.3	6.1	3.7	3.8	5.0	3.9
95th percentile	6.5	7.6	5.3	5.3	7.1	4.7
Maximum	8.2	8.2	6.0	7.3	7.7	5.4

5.2.1.2 Differences between the soil layers

The pH increases significantly with depth for loess soils (Table 63). This can be explained by the combination of the effect of acid input on top of the soil and the presence of (remnants of) calcaric material in the subsoil at some locations. The median values for the pH(H_2O) and pH(KCl) of the humus layer of the loess soils are slightly higher than those in the topsoil, namely 4.3 and 3.5 respectively (Section 4.2.1).

In the peat soils there is only a slight increase in pH(H_2O) and pH(KCl) (Table 63). The change, however, is significant and very regular. The largest change occurs between the 0-10 cm layer and the 10-30 cm layer. This pattern can be explained by the acidic input on top of the profile and the buffering by groundwater flow and the nearby mineral subsoil. Unlike the general pattern, the pH values in the low moor peat soils sharply increase from the first layer (median pH(KCl) = 2.9) to the fourth layer (median pH(KCl) = 4.5). This pattern indicates, that in the low moor area the deeper layers are influenced by less acidic surface water of seepage water.The median values for the pH(H_2O) and pH(KCl) for the humus layer of peat soils are considerably higher than those in the layer 0-10 cm, namely 4.2 and 3.4 respectively (Section 4.2).

The increase with depth in pH(H_2O) and pH(KCl) does not occur for the clay soils. If there is any trend, it even is a weak, but significant decrease (Table 63). This indicates that a significant effect of acidic input on top of the soil profile is not very likely. Probably the internal proton production by humus transformations is also an important factor.

Table 63 Median values (per soil layer) of the pH(H_2O) and the pH(KCl) in the mineral soil

Soil layer	pH(H_2O)	pH(KCl)
<u>*Loess soils:*</u>		
0 - 10 cm	4.0	3.4
10 - 30 cm	4.4	3.9
30 - 60 cm	4.4	4.0
60 - 100 cm	4.5	4.0
Expl. variance (% R^2adj)	*58*	*51*
<u>*Clay soils:*</u>		
0 - 10 cm	6.1	5.2
10 - 30 cm	6.1	4.9
30 - 60 cm	6.0	5.0
60 - 100 cm	6.0	5.0
Expl. variance (% R^2adj)	*66*	*53*
<u>*Peat soils:*</u>		
0 - 10 cm	3.7	2.8
10 - 30 cm	3.6	3.0
30 - 60 cm	3.7	3.0
60 - 100 cm	3.8	3.0
Expl. variance (% R^2adj)	*21*	*40*

5.2.1.3 Relations with the environmental characteristics

Soil types

Within the loess soils, the Fluvisols has higher pH values than the other soil types (Table 64). The pH values of this soil type are at almost the same level as those for the two soil type clusters for clay soils, i.e. ca 6.0 for the pH(H_2O) and ca 5.0 for the pH(KCl). For the clay soils, the medium-textured soils have slightly higher pH values than the fine-textured soils.

The highest pH values for peat soils occur in the low moor area, probably due to the nearby presence of surface water. Within the high moor area, the Fibric Histosols in this area are only slightly more acidic than the Terric Histosols.

Statistical analysis

For the loess soils, the differences in the pH values in the mineral soil are explained best by the soil type in the simple model, together with the deposition level in the full statistical model with all environmental factors (Table 65). This pattern indicates, that the deposition of acid substances have a significant influence on the variation in the pH of the mineral soil. This pattern also reflects the more pronounced pattern found for the humus layer (Table 36). Furthermore, there is some evidence that most of the soil type in the loess soils are affected be acid deposition, since the interaction term between soil type and deposition level was not selected. Inclusion of this interaction term would have been the indication of different deposition effects in different soil types.

Table 64 Median values of the pH(H_2O) and the pH(KCl) in the mineral soil as a function of the soil type [1].

Soil type	pH(H_2O)	pH(KCl)
Loess soils:		
Cambisol in sandy loess	4.3	4.1
Cambisol in loamy loess	4.3	3.8
Haplic and Gleyic Luvisol	4.3	3.8
Eutric and Calcic Fluvisol	5.9	4.9
Expl. variance (% R^2adj)	*33*	*28*
Clay soils:		
Eut. Fluvisol, med. texture	5.9	4.8
Eut. Fluvisol, fine texture	6.0	4.7
Calc. Fluvisol, fine texture	7.3	6.9
Expl. variance (% R^2adj)	*37*	*40*
Peat soils:		
Fibric Histosol, high moor	3.5	2.6
Terric Histosol, high moor	3.6	2.8
Fibric Histosol, low moor	4.1	3.4
Expl. variance (% R^2adj)	*26*	*34*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

For both the clay and peat soils, the variation in the pH values is explained best by the combination of soil type and drainage class, both in the simple model with only soil type and drainage class as explaining factor, and in the full statistical model with all environmental factors (Table 65). The pH of the clay soils and also of the Terric Histosol is also positively correlated with the deposition levels. No significant relationship was found for the two Fibric Histosol clusters within the peat soils. The positive correlation for the other soils is opposite as could be expected, because higher deposition levels are correlated with higher pH values. Probably, a different factor plays a role in the variation after the inclusion of soil type and drainage class, which is not in the model, or the variation within these soil type clusters and drainage clusters is correlated somehow with the deposition level.

Table 65 Best explaining environmental characteristics for the pH(H_2O) and the pH(KCl) in the mineral soil, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	$\%R^2_{adj}$	Sign.[3]	Factors	$\%R^2_{adj}$	Sign.[3]
Loess soils:						
pH(H_2O)	So	33	***	So + Dp_t	53	***
pH(KCl)	So	28	**	So + Dp_t + La	56	***
Clay soils:						
pH(H_2O)	So + Dr	48	***	So + Dr + Dp_{so}	57	***
pH(KCl)	So + Dr	51	***	So + Dr + Dp_{so}	61	***
Peat soils:						
pH(H_2O)	So + Dr_c	40	***	So + Dr_c + Dp_{no}.So	62	***
pH(KCl)	So + Dr_c	50	***	So + Dr_c + Dp_{no}.So	70	***

[1] Simple model: analysis only with 'Soil Type' and 'Drainage Class (coding cf. Section 2.4).
[2] Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).
[3] Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

5.2.2 Cation exchange capacity (CEC)

5.2.2.1 Observed variation

Table 66 gives an overview of the distribution of the cation exchange capacity (CEC) of the mineral soil samples. For the peat soils, the CEC is also expressed as the CEC of the organic matter by contributing all CEC to the organic matter content. This makes it possible to compare the CEC of samples with different contents of organic matter. The results of this last procedure are not presented for loess and clay soils, because the CEC of these soils can not only be contributed to the organic matter content, but also to the clay content.

The highest values for the CEC are found for the peat soils, with a median value of 415 $mmol_c\ kg^{-1}$ and a maximum value of 1130 $mmol_c\ kg^{-1}$ (Table 66). These high values are caused by the high organic matter content of these soils. The clay soils also have high values for the CEC (median value: 313 $mmol_c\ kg^{-1}$), but here the CEC can mainly be contributed to the CEC of the clay minerals. The lowest values for the CEC are found for loess soils (median value: 58 $mmol_c\ kg^{-1}$), because these soils lack the high organic matter contents of the peat soils and have lower clay contents than the clay soils. For all parent materials, the CEC values are higher than for the sandy soils (De Vries & Leeters, 1999). The CEC of sandy soils can only be contributed to relatively low contents of organic matter. Most sandy soils do not contain a significant clay content.

For the peat soils, the CEC (Table 66) do not differ much, which is mainly due to the high organic matter contents. The high maximum values of the CEC(O.M.) and the CEC(O.M.)$_{pH(KCl)=6.5}$ indicate that in some samples also a considerable clay content contributed to the CEC. The samples with highest CEC of the organic matter are the same as the samples with the high content of mineral particles. In peat soils (without a significant clay content) the complete CEC can be attributed to the organic matter contents. This makes it possible to calculate the CEC of the organic matter (CEC in O.M., Table 66). Under the assumption of the linear correlation between the CEC of the organic matter and the pH, also a theoretical value of the CEC of the organic matter at pH(KCl)=6.5 can be calculated.

In loess and clay soils the CEC can be attributed to the clay and the organic matter contents. Therefore, it is not possible to calculate the CEC of the clay or the CEC of the organic matter directly from the CEC and the clay or organic matter content. This problem was overcome by the use of multiple linear regression, which included the organic matter contents (in relation with the pH(KCl) and the clay content. This procedure is based on the linear relationship between the CEC and the organic matter and clay contents. The following regression equations were applied:

$$CEC = c_0 + c_1 * O.M. * pH(KCl) + c_2 * Clay$$
$$CEC = c_0 + c_1 * O.M. * pH(KCl) + c_2 * Clay * SoilType$$

The second equation includes also the soil type, since the CEC(clay) could also be a function of the soil types, since the soil types could contain different parent materials and therefore different clay minerals. The values for the $CEC(O.M.)_{pH(KCl)=6.5}$ and CEC(clay) were calculated as the predictions for an organic matter contents of 1000 g kg^{-1} (and pH(KCl=6.5) and for a clay content of 1000 g kg^{-1}, respectively. For the $CEC(O.M.)_{pH(KCl)=6.5}$ a distribution was generated by the assignation of the residuals of the regression to the organic matter content, whilst the value of the clay content was expected to be constant (which, of course, is a simplification). A correction procedure was built in for unrealistically low values (< 0.5*median) and unrealistically high values (> 2*median).

For the clay soils the first regression results in an estimated CEC(clay) of 671 $mmol_c$ kg^{-1} (R^2_{adj} = 54%). The addition of the soil type does not improve this result. For the loess soils, however, the CEC(clay) appears to be correlated with the soil type. Only the pairwise differences between the Fluvisols and the other types appear to be significant (t-probability < 0.001), whereas the t-probabilities of the other possible pairs varies between 0.010 and 0.093. Therefore, only the difference between the Fluvisol loess soils and the cluster of the other three soil types was included in the model. The estimations for the CEC(clay) of the loess soils were 782 $mmol_c$ kg^{-1} for the Fluvisols and 360 $mmol_c$ kg^{-1} for the other soil types (R^2_{adj} = 57%, compared to 40% for the regression without soil type). The value for the fluvial loess soils is comparable with the value for the regular clay soils, which indicates that the mineral composition of the clay fraction are similar. For the loess soils the calculated $CEC(O.M)_{pH(KCl)=6.5}$ varies between 459 and 1438 $mmol_c$ kg^{-1}, with a median value of 919 $mmol_c$ kg^{-1}. For the clay soils the $CEC(O.M)_{pH(KCl)=6.5}$ varies between 732 and 1234 $mmol_c$ kg^{-1}, with a median value of 1111 $mmol_c$ kg^{-1}. The results for the clay soils are comparable with the results for the peat soil (Table 66), whereas the results for the loess soils are considerably lower. In the humus layer the opposite pattern was found (Table 37).

Table 66 Minimum, maximum, 5th, 50th and 95th percentiles of the contents and total pools (in the top 100 cm) of the CEC in the mineral soil

Statistic	CEC ($mmol_c\ kg^{-1}$)					CEC ($kmol_c\ ha^{-1}\ dm^{-1}$)		
	Loess	Clay	Peat	*1)*	*2)*	Loess	Clay	Peat
Minimum	7.2	63	121	*333*	*526*	27	126	58
5th percentile	16	95	278	*351*	*810*	37	146	59
50th percentile	58	313	415	*457*	*1 139*	81	396	69
95th percentile	156	447	708	*1 205*	*1 683*	235	540	123
Maximum	281	512	1 130	*1 513*	*1 869*	363	554	190

1) CEC of organic matter (only for peat soils)
2) CEC of organic matter at pH(KCl)=6.5 (only for peat soils)

5.2.2.2 Differences between the soil layers

For the loess soils, the highest CEC values occur in the topsoil and in the subsoil, with the lowest values in the intermediate layers (Table 67). The high CEC values in the topsoil can be explained by the organic matter content of this layer (Table 53), whereas the high values in the subsoil can be explained by the higher clay content in this layer.

Table 67 Median values (per soil layer) of the contents, contents in the organic matter and pools of the CEC in the mineral soil

Soil layer	CEC content ($mmol_c\ kg^{-1}$)			CEC pool ($kmol_c\ ha^{-1}$ dm-1)
	measured	in Org.Matter	in $O.M._{pH=6.5}$	
Loess soils:				
0 - 10 cm	67			95
10 - 30 cm	40			61
30 - 60 cm	42			61
60 - 100 cm	72			112
Expl. variance (% R^2adj)	*2*			*0*
Clay soils:				
0 - 10 cm	271			337
10 - 30 cm	279			368
30 - 60 cm	319			419
60 - 100 cm	344			456
Expl. variance (% R^2adj)	*10*			*21*
Peat soils:				
0 - 10 cm	401	450	1 123	67
10 - 30 cm	421	470	1 180	68
30 - 60 cm	429	493	1 164	71
60 - 100 cm	419	432	1 041	66
Expl. variance (% R^2adj)	*5*	*7*	*1*	*6*

Only the CEC of the clay soils shows a clear and significant trend with the depth (cf. Table 67). The CEC increases regularly from 271 to 344 $mmol_c\ kg^{-1}$. This pattern is related to a similar pattern in the clay content (Table 16), since the values for the CEC of the organic matter and the CEC of the clay do not show a significant depth-related pattern. The decrease with depth of the organic matter contents (Table 53) seems of less importance. For the peat soils, the CEC changes only little with depth, also if the values are corrected for the admixture with mineral particles and the differences in pH.

The CEC of the organic matter (at pH(KCl)=6.5) and the CEC of the clay do not show significant changes with the depth. The patterns with depth of the CEC pools primarily reflect the differences in thickness (which causes the high values for the accounted variance), and secondary the differences in CEC content.

5.2.2.3 Relations with the environmental characteristics

Soil types

Within the loess soils, the lowest values for the CEC occur in the Cambisols in sandy loess (Table 68). This result resembles most the results for the sandy soils (De Vries & Leeters, 1999). The highest values occur in the Fluvisols. The CEC of the organic matter and the CEC of the clay are also highest for the fluvisols. This result resembles most the result for the medium textured clay soils.

Table 68 Median values of the contents and total pools of the CEC in the mineral soil as a function of the soil type [1].

Soil type	CEC content ($mmol_c\ kg^{-1}$)			CEC pool ($kmol_c\ ha^{-1}\ dm^{-1}$)
	measured	in Org.Matter	in $O.M._{pH=6.5}$	
<u>Loess soils:</u>				
Cambisol in sandy loess	23			44
Cambisol in loamy loess	58			86
Haplic and Gleyic Luvisol	64			98
Eutric and Calcic Fluvisol	130			197
Expl. variance (% R^2adj)	*43*			*46*
<u>Clay soils:</u>				
Eut. Fluvisol, med.-texture	139			223
Eut. Fluvisol, fine-texture	363			468
Calc. Fluvisol, fine-texture	339			465
Expl. variance (% R^2adj)	*47*			*45*
<u>Peat soils:</u>				
Fibric Histosol, high moor	421	442	1 116	65
Terric Histosol, high moor	423	460	1 166	69
Fibric Histosol, low moor	378	541	1 103	88
Expl. variance (% R^2adj)	*0*	*15*	*0*	*19*

1) Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

The differences in CEC of the soil types in loess and clay soils can mainly be contributed to differences in the clay content, since the differences in CEC of the organic matter and CEC of the clay are relatively small and the pattern of the organic matter content would result in a trend in the opposite direction. The values for the CEC pools show the same pattern as the values for the CEC content. Within the peat soils, the largest values for the CEC occur in the high moor area (Table 68). However, recalculated to amounts per hectare and corrected for the organic matter content, the highest values are found for the locations in the low moor area.

Statistical analysis

For the loess soils, the variation in the CEC and the CEC pools is explained well by the soil type (Table 69). After the addition of the other environmental factors, the deposition levels also contribute significantly to the explained variance. The influence of the deposition level may depend on the pH dependency of the CEC of the organic matter content (deposition affects the CEC through its effect on the soil pH) or on a correlation between soil type and deposition level.

The variation in the CEC and CEC pool in the clay soils is explained well by the combination of soil type and drainage class. When using the complete model, also the deposition levels were included. There are two possible reasons for this inclusion (i) the deposition level is correlated with the variation in clay contents within the soil types, or (ii) that the impact of the relationship between the deposition levels through the soil pH is large enough to be revealed, despite the large contribution of the clay content to the total CEC. Further elaboration of the interaction term between deposition and soil type reveals the strongest relationship between deposition level and CEC was found for the light textured soils. This indicates that the second solution could well be correct.

Table 69 Best explaining environmental characteristics for the contents and total pools of the CEC in the mineral soil, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	$\%R^2_{adj}$	Sign.[3]	Factors	$\%R^2_{adj}$	Sign.[3]
Loess soils:						
CEC content	So	43	***	So + Dp_n	53	***
CEC pool	So	46	***	So + Dp_n	54	***
Clay soils:						
CEC content	So + Dr_c	63	***	So + Dr_c + Dp_{so} + Dp_{so}.So	78	***
CEC pool	So + Dr_c	63	***	So + Dr_c + Dp_{so}.Dr + Ca	82	***
Peat soils:						
CEC content	Dr	1	-	-	0	-
of O.M.	So + Dr_c	25	*	So + Dr_c + Dp_{no}.So + Ds	38	***
of O.M./pH=6.5	-	0	-	-	0	-
CEC pool	So + Dr_c	27	*	Dr_c + Dp_{no} + Di	50	***

1) Simple model: analysis only with 'Soil Type' and 'Drainage Class (coding cf. Section 2.4).
2) Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).
3) Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

The CEC variables of the peat soils show only weak relationships with the soil type and/or the drainage class, when analysing the simple model. When analysing the complete model, the deposition level of NO_x contributed significantly to the explained variance of the CEC(O.M.) and the CEC pool, in combination with the drainage class. The low explained variance of the CEC at standardized conditions ($CEC(O.M.)_{pH=6.5}$), however, indicates that this relationship is mainly an effect of the pH dependency of the CEC. Therefore, also the results of the other CEC variables for the peat soils seem to be strongly affected by the relationship between the CEC, the pH and the deposition levels (compare with the soil solution results, Section 5.2.1).

5.2.3 Exchangeable cations

5.2.3.1 Observed variation

Table 70 gives an overview of the variation in the exchangeable cation contents of the mineral soil. These results are expressed as percentages of the CEC. Only the most important cations are presented: the acid cations H and Al and the sum of the base cations (Ca, Mg, K and Na). Where relevant, the results of the separate base cations and the results on the other cations, such as NH_4, Fe and Mn are discussed in the text.

There is a great variation of the occupation of the CEC within the three parent materials (Table 70). On average, the CEC of the loess soils is mainly occupied by Al (median Al saturation 60%, maximum 84%). The CEC of the clay soils is mainly occupied by base cations (median base saturation 88%, maximum 100%). The CEC of the peat soils is almost equally saturated with H and base cations (median values 38% and 43%, respectively). However, for all three parent materials, the maximum base saturation is (almost) 100%, with minimum H saturation and Al occupation of 0%.

The most important base cation is Ca, especially for the clay soils, with median values of 6.8%, 73% and 26% for the loess, clay and peat soils, respectively. The highest values for the Fe and NH_4 occupation are found for the peat soil, with median values of 3% for both ions and a maximum values of 20% and 10%. The highest Mn occupation is found for the clay soils with a median value of 2% and a maximum value of 29%.

Table 70 Minimum, maximum, 5th, 50th and 95th percentiles of the exchangeable cation content (in percentage of the CEC) in the mineral soil

Statistic	H (%)			Al (%)			B.C. [1] (%)		
	Loess	Clay	Peat	Loess	Clay	Peat	Loess	Clay	Peat
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	4.2	9.7	18
5th percentile	1.9	0.0	0.0	0.0	0.0	0.1	5.1	38	20
50th percentile	14	8.5	38	60	0.0	4.9	13	88	43
95th percentile	24	21	66	81	28	22	90	100	94
Maximum	35	44	75	84	47	34	100	100	99

[1] B.C. (base cations) = Ca + Mg + K + Na

The wide ranges of values found here do also occur for the sandy soils (De Vries & Leeters, 1999). In general the base saturation of the parent material observed in this survey, is, however, higher than the base saturation of the sandy topsoils (0-30 cm), which has a median value of 6%. The median value of the Al occupation for the loess soils is almost as high as for the sandy soils (median value 66%). The

H occupation of the loess and clay soils is lower and the H occupation of the peat soils is higher than found for the sandy soils.

The exchangeable cation pools also show very wide ranges (Table 71). The largest pools of exchangeable base cations occur on clay soils. These figures combine the large values for the CEC for clay soils and the high base saturation. The loess soils have the smallest pools of exchangeable base cations, although the maximum value is close to those of the clay and peat soils. The largest pools, by far, of exchangeable Al occur on the loess soils, thus reflecting the large Al occupation of these soils. The loess soils also have the smallest pools of exchangeable H. For clay and peat soils, the pools of exchangeable H for clay and peat soils are about twice as large.

Table 71 Minimum, maximum, 5th, 50th and 95th percentiles of the total pools of exchangeable cations in the mineral soil

Statistic	H ($kmol_c\ ha^{-1}\ dm^{-1}$)			Al ($kmol_c\ ha^{-1}\ dm^{-1}$)			B.C. [1] ($kmol_c\ ha^{-1}\ dm^{-1}$)		
	Loess	Clay	Peat	Loess	Clay	Peat	Loess	Clay	Peat
Minimum	0.27	0.32	4.9	0.00	0.01	0.02	2.7	80	13
5th percentile	3.4	3.7	4.9	0.37	0.10	1.6	2.9	84	14
50th percentile	13	28	24	35	2.4	4.2	12	365	36
95th percentile	23	67	43	64	36	14	220	500	94
Maximum	35	72	44	85	45	14	318	506	178

[1] B.C. (base cations) = Ca + Mg + K + Na

5.2.3.2 Differences between the soil layers

The trends with the depth in exchangeable cation fractions are very different for the three parent materials (Table 72). For the loess soils, the topsoil (0-10 cm) contrasts with the other layers by its higher base saturation and its lower Al occupation. On the contrary, the highest Al occupation and the lowest base saturation occur in the second layer (10-30 cm) with a slight levelling further down.

The clay soils show a very clear increase with the depth for the base saturation and a very clear decrease for the H and Al occupation (though on a very low level for Al). Especially in the topsoil under stands with oak or beech high values for the Al occupation have been found. The peat soils also show this increase with the depth for the base saturation and the decrease for the H and Al occupation, but on different levels.

Table 72 Median values (per soil layer) of the exchangeable cation content (in percentage of the CEC) in the mineral soil

Soil layer	Exchangeable cation content (%)		
	H	Al	B.C. [1]
Loess soils:			
0 - 10 cm	15	48	17
10 - 30 cm	13	69	10
30 - 60 cm	15	68	11
60 - 100 cm	14	64	14
Expl. variance (% R^2adj)	*4*	*9*	*0*
Clay soils:			
0 - 10 cm	11	1.1	83
10 - 30 cm	10	0.2	85
30 - 60 cm	7.5	0.0	90
60 - 100 cm	4.9	0.0	93
Expl. variance (% R^2adj)	*23*	*48*	*24*
Peat soils:			
0 - 10 cm	43	9.2	33
10 - 30 cm	38	7.3	44
30 - 60 cm	35	4.0	60
60 - 100 cm	38	2.2	58
Expl. variance (% R^2adj)	*23*	*29*	*54*

[1] B.C. (base cations) = Ca + Mg +K + Na

5.2.3.3 Relations with the environmental characteristics

Soil types

Within the loess soils, the lowest base saturation and the highest Al occupation occur in the Cambisols in sandy loess (Table 73). These results show the best similarity with the results found for the sandy soils (De Vries & Leeters, 1999). By far the highest base saturation and the lowest Al occupation are found for the (Calcic) Fluvisol cluster. The results for this cluster are similar with those found for the clay soils. There is only little difference between the two soil type clusters for the clay soils. For the peat soils the largest base saturation and the smallest H occupation are found in the low moor area. These results indicate that the nearby presence of mesotrophic surface water might have a buffering influence in the soil profile of these soils. Within the set of locations in the high moor area, the Fibric Histosols have a lower base saturation an a higher H occupation than the Terric Histosols. These results indicate that the more earthified soils are less acidified.

Statistical analysis

For the loess soils, the variation in the H and Al occupation and the base saturation are explained well by the soil type (Table 74). The addition of the drainage class results in a small increase in the explained variance for the H occupation, compared to the model with soil type only (Table 73). The completion of the statistical model with all other environmental characteristics results in the addition of the deposition levels to best explaining model. For the H occupation the impact of the deposition is different for the various soil types.

Table 73 Median values of the exchangeable cation content (in percentage of the CEC) in the mineral soil as a function of the soil type [1]*.*

Soil type	Exchangeable cation content (%)		
	H	Al	B.C. [2]
Loess soils:			
Cambisol in sandy loess	14	72	8.3
Cambisol in loamy loess	15	64	12
Haplic and Gleyic Luvisol	15	57	19
Eutric and Calcic Fluvisol	10	0.2	88
Expl. variance (% R^2adj)	*17*	*29*	*34*
Clay soils:			
Eut. Fluvisol, med.-texture	9.3	0.0	84
Eut. Fluvisol, fine-texture	9.6	0.0	87
Calc. Fluvisol, fine-texture	0.0	0.0	100
Expl. variance (% R^2adj)	*46*	*17*	*14*
Peat soils:			
Fibric Histosol, high moor	57	4.9	30
Terric Histosol, high moor	37	5.1	45
Fibric Histosol, low moor	11	5.0	66
Expl. variance (% R^2adj)	*60*	*0*	*32*

1) Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

2) B.C. (base cations) = Ca + Mg + K + Na

The strongest relationship between the deposition level with the H occupation was found for the Fluvisols (within the loess soils). This pattern indicates, that the variation in the composition of the CEC is significantly influenced by differences in atmospheric deposition, which indicates that the atmospheric deposition onto these soils is mainly buffered by cation exchange. The tree species is also important for the base saturation. These results, together with actual values from Table 73, indicate that the exchange sites released by base cations are mainly filled with H for the Fluvisols and with AL for the other soil types. This corresponds with the Al concentrations in the soil solution for these soil types (Table 102).

The occupation of the CEC of the clay soils by the various compounds is mainly correlated with the factors of the simple model: soil type and drainage class (Table 74). The variation in the H occupation and the base saturation seems also to depend also on the deposition level (of SO_x). The effect of deposition is different for the various soil types, because the interaction term is significantly included. The variables in the calcaric soils are not affected by the deposition level, whereas there is a clear correlation between the deposition level and the H occupation in the non-calcareous soil types. This indicates that the acid deposition is buffered by cation release from exchange complex. The actual base saturation figures, however, indicate that this buffering occurs in a non-harmful range (Table 73) and that this buffer is large enough to buffer acidic inputs for a long time.

For the peat soils, the H occupation and the base saturation are explained significantly by the combination of soil type and drainage class (Table 74). The addition of the drainage class to the soil type results in a significant increase of the explained variance, compared to the soil type as an single factor (Table 73). For the Al occupation, the combination of soil type and drainage gives also the best correlation, but this relation is not significant. The tree species does give a significant explanation of the observed variation. The highest Al occupation was found under the species cluster with oak. The tree species also give much extra explanation in the base saturation.

Table 74 Best explaining environmental characteristics for the exchangeable cation content (in percentage of the CEC) in the mineral soil, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	$\%R^2_{adj}$	Sign.[3]	Factors	$\%R^2_{adj}$	Sign.[3]
Loess soils:						
Exch. H (%)	So + Dr	18	*	So + Dp_{no}.So	60	***
Exch. Al (%)	So	29	**	So + Dp_{so}	46	***
Exch. B.C. (%)	So	34	***	So + Dp_{so} + Tr + He	66	***
Clay soils:						
Exch. H (%)	So + Dr	47	***	So + Dp_{so} + Dp_{so}.So	69	***
Exch. Al (%)	So + Dr_c	32	**	So + Dr_c	32	**
Exch. B.C. (%)	So + Dr	23	*	So + Di + Dp_{so}.So	67	***
Peat soils:						
Exch. H (%)	So + Dr	69	***	So + Dr	69	***
Exch. Al (%)	Dr_c + So	13	-	Tr	29	***
Exch. B.C. (%)	So + Dr	41	**	So + Dr + La + Tr	47	***

1) Simple model: analysis only with 'Soil Type' and 'Drainage Class (coding cf. Section 2.4).
2) Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).
3) Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

5.2.4 Remaining buffer capacity in relation with present loads of acidity

Concepts

In this section the values for the pools of exchangeable cations are related to the concept of critical loads. This is done, since most of the investigated soils in loess, clay and peat are in the buffering range of the exchange of base cations from the exchangeable cation pool. Therefore, the acidification status of the soils can be related to the depletion of the pools of exchangeable base cations. This section is focused on the risks of the present loads, given the present chemical composition of the soil. This risk is estimated by the number of years left, till the present load will actually result in enhanced (riskfull) concentrations of H and Al in the soil solution. This critical period is defined as the period that is left to deplete the percentage of exchangeable base cations down to 10% of the CEC on average over the top 40 cm of the soil profile. It is presumed that the exceedance of this limit is closely related to a sharp rise in H and Al concentrations in the soil solution (De Vries et al., 1989; De Vries, 1991; 1994).

Exceedances of critical deposition levels were calculated by subtracting this critical deposition level was subtracted from the present load of S and N. It was assumed that these excess loads were fully buffered by the release of exchangeable cations, as a simplification of the *Simple Mass Balance* (SMB) model (De Vries, 1994; 1996; Sverdrup & de Vries, 1994). As a first estimate, the period before acid deposition would become harmful, was therefore estimate by

$$t = (BC_{pres} - BC_{crit}) \, / \, ((S+N)_{td,pres} - (S+N)_{td,crit})$$

in which BC_{pres} and BC_{crit} are the present and critical (BS=10%) pools of exchangeable base cations, respectively ($mol_c\ ha^{-1}$), and $(S+N)_{td,pres}$ and $(S+N)_{td,crit}$ are the present and critical load of the sum of S and N, respectively ($mol_c\ ha^{-1}\ a^{-1}$). This equation is based on the assumptions that (i) the present load stays equal in the future and (ii) the critical load equals all acid consuming processes except base cation exchange.

The calculation of critical loads is carried out by the use of the simple mass balance model (SMB). The simple mass balance model calculates critical loads, by including processes influencing acid production and consumption during infinite time only, according to the following equation:

$$(S+N)_{td}(crit) = BC_{td} + BC_{we} + BC_{gu} + N_{gu} + N_{im} + N_{de} + Ac_{le}(crit)$$

where BC are base cations (Ca+Mg+K), td is total deposition (dry and wet), we is weathering, gu is growth uptake, de is denitrification and Ac_{le} is the critical acidity leaching. The following simplifications and assumptions were made in the implementation of the SMB equation, since there were only few data on the different terms of the SMB equation:

- The result of the terms $BC_{td} + BC_{gu}$ is considered to be 0.
- The term BC_{we} was estimated as a function of the soil type and more precisely of the sand, silt and clay content and the organic matter contents of the soils. This is probably the less certain term in the critical load formula.
- The result of the terms $N_{gu} + N_{im} + N_{de}$ was estimated as a function of the N deposition and the drainage class. The N concentrations in the subsoil (Chapter 6) were used to verify the results.
- The acidity leaching is related to the precipitation excess (which was a function of tree species, drainage class and canopy coverage) and the concentrations of H and Al in the subsoil. For soils with a base saturation < 10% or a pH in the subsoil < 4 the acidity leaching was estimated using the initial (measured) concentrations. For soils with a base saturation > 10% or a pH > 4, a gradual increase in H and Al leaching was assumed, related to the decrease in base saturation.
- A reduction factor was included for the 'effective acid deposition' on peat soils, if the location was near surface waters, which could have a buffering effect through ground water streams.

The estimated values for each term or combination of terms resulted in a (average) critical load or critical deposition level per plot.

For some locations on clay and loess this period of base cation depletion was preceded by a period of decalcification, if any carbonates were present in the top 40 cm. The decalcification rate was set at 10 000 $mol_c\ ha^{-1}\ a^{-1}$. It is assumed that the rate of decalcification is mainly a natural process, which not affected by the level of acid deposition. The following additional assumptions were made: (i) \ there is nu buffering effect by base cations from ground water and (ii) the calculations are not affected by the change in CEC, related to the change in pH.

Overall results

The amount of available exchangeable base cations is already depleted for most loess soil and almost depleted for some peat soils and even some clay soils (Table 75). This means that the soil solution composition at these locations is directly adverse affected the present acid load.

Table 75 Minimum, maximum, 5th, 50th and 95th percentiles of present loads of acidity, the available pools of carbonates and exchangeable cations in the top 40 cm and the time left before these pools will be depleted

Statistic	Carbonate pool[2] ($kmol_c\ ha^{-1}$)	Time to deplete carbonate pool (years)	Acid deposition[1] ($mol_c\ ha^{-1}\ a^{-1}$)	$BC_{exch.}$ pool ($kmol_c\ ha^{-1}$)		Time to deplete BC_{exch} pool (years)		
				BS>25%	BS>10%	BS>25% buffered[2]	BS>10% buffered[2]	BS>10% + ac. leaching[2]
Loess soils:								
Minimum	0	0	3 278	0	0	0	0	0
5th percentile	0	0	4 738	0	0	0	0	0
50th percentile	0	0	5 419	0	5	0	2	5
95th percentile	0	0	6 729	668	813	281	343	366
Maximum	414	41	6 895	810	1 013	400	499	547
Clay soils:								
Minimum	0	0	4 391	51	130	15	38	48
5th percentile	0	0	5 810	77	151	25	49	55
50th percentile	9	1	7 173	883	1 103	390	488	520
95th percentile	1 557	156	8 110	1 450	1 771	801	978	1 314
Maximum	4 452	445	8 110	1 490	1 800	989	1 216	1 396
Peat soils:								
Minimum	0	0	3 988	0	27	0	11	23
5th percentile	0	0	3 988	0	29	0	14	23
50th percentile	0	0	5 245	64	104	54	80	91
95th percentile	0	0	7 116	173	235	277	353	408
Maximum	0	0	8 114	534	654	279	373	458

1) The same deposition figures as presented in Section 3.1.
2) Buffered = all acidity is buffered by the release of exchangeable base cations ; + ac.leaching = part of the acidity is not buffered but leached directly to the subsoil (see text).

Some loess soils and most peat and clay soils still have sufficient base cations to buffer the inputs of acidity for a considerable period. For few locations on loess and clay soils the critical load is not exceeded, even at the present deposition level. For all three soil groups the remaining time is mostly determined by the pool of exchangeable cations. The pools of carbonates do hardly affect the results, since the pool of carbonates in these soils is relatively small compared to the pool of exchangeable cations and related to the speed of depletion of both pools.

Results per soil type

The Cambisols in sandy loess within the loess soils are already completely depleted of exchangeable base cations (Table 76). This means that these soils are already directly affected by atmospheric inputs of acidic compounds. The pools of exchangeable cations in the Cambisols in loamy loess and the Luvisols are also almost depleted, but the soil solution in the subsoil of the Cambisols in loamy loess indicates that a considerable part of the acidic inputs are directly transported through the soil profile, resulting in a relatively high level of acidity leaching and a longer period. The Fluvisol are relatively invulnerable for the impact of acid deposition.

Table 76 Present loads of acidity, available pools of carbonates and exchangeable cations in the top 40 cm and the time left before these pools will be depleted as a function of the soil type [1].

Soil type	Carbonate pool ($kmol_c\ ha^{-1}$)	Time to deplete carbonate pool (years)	Acid deposition[2] ($mol_c\ ha^{-1}\ a^{-1}$)	BC_{exch} pool $kmol_c\ ha^{-1}$		Time to deplete BC_{exch} pool (years)		
				BS>25%	BS>10%	BS>25% buffered[3]	BS>10% buffered[3]	BS>10% + Ac.leaching
Loess soils:								
Cambisol, sandy l.	0	0	5 857	0	0	0	0	0
Cambisol, loamy l.	0	0	5 339	0	3	0	1	3
Hapl./Gl. Luvisol	0	0	5 363	0	24	0	8	11
Eutr/Calc. Fluvisol	0	0	4 940	493	605	179	221	234
Clay soils:								
Eut. Fluvisol, med.	0	0	6 858	514	637	142	176	183
Eut. Fluvisol, fine	0	0	7 203	1 109	1 407	452	563	597
Calc. Fluvisol	1 193	119	7 179	1 368	1 645	494	595	616
Peat soils:								
Fb. Histosol, h.m.	0	0	5 147	0	30	0	14	23
Tr. Histosol, h.m.	0	0	4 812	0	26	0	11	22
Fb. Histosol, l.m.	0	0	5 700	56	95	65	100	117

1) Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.
2) The same deposition figures as presented in Section 3.1.
3) Buffered = all acidity is buffered by the release of exchangeable base cations ; + ac.leaching = part of the acidity is not buffered but leached directly to the subsoil (see text).

The carbonate pools of the calcaric Fluvisols within the clay soils are large enough to last for more than one century (Table 76). After this century, the pool of exchangeable base cations is still large enough to buffer acidic inputs for many more centuries. The same is true for the exchangeable base cation pools of the fine-textured Eutric Fluvisols. The pool of exchangeable base cations in the medium-textured Eutric Fluvisols is considerably smaller and the period before depletion is much shorter. The median value, however. is still almost two centuries, indicating that even this soil type is mostly not vulnerable for acidic inputs.

The vulnerability for acidic inputs of the peat soils decreases in the presented order of soil types (Table 76). In the peat soils acidic inputs are not only buffered by the release of exchangeable base cations, but also by nitrogen related processes, like denitrification and hampered nitrification. Furthermore, other processes related to water-logged conditions, mineralization after drainage, nitrogen production by alder and buffering by nearby surface water may play a role. In general, the high moor soil types can be considered vulnerable for acidification. In the low moor peat soils the various processes (including exchangeable base cation release) result in a relatively low vulnerability of acidification.

5.3 Oxalate extractable aluminium, iron and phosphorus

5.3.1 Observed variation

This section gives an overview of the variation the contents, pools and ratios of the oxalate extractable aluminium (Al_{ox}), iron (Fe_{ox}) and iron (Fe_{ox}) content of the mineral soil (Tables 77, 78 and 79). The contents of Al_{ox} and Fe_{ox} form an important pools of easily weatherable minerals, e.g. for acidification. The P_{ox} contents gives an indication of the amount of easily available P. The ratio with the P_{tot} contents gives an indication about the fraction of all P that is easily available. The ratio with the Al_{ox} and Fe_{ox} give an indication of the level of fixation of the P_{ox} in the soil.

The highest Al_{ox}, Fe_{ox} and P_{ox} contents are found in the clay soils, whereas the lowest values are found for peat soils (Table 77). The largest (relative) differences, based on the median values, were found for P_{ox}, whereas the smallest differences were found for P_{ox}. The low values for the Al_{ox} and Fe_{ox} contents of peat soils can be explained from the fact that a large part of these mineral in the 'mineral' soil types consist of secondary minerals which originate from the weathering of primary minerals. In peat soils the Al_{ox} mainly originate from the accumulation of Al in organic matter, liberated from clay minerals (like in mineral soils), whereas the Fe_{ox} contents also originate from the accumulation of seepage ions. The availability of clay minerals as a source for the formation of Al_{ox} (and Fe_{ox}) is much larger for mineral soils (sand, loess and clay) than for organic soils (peat).

Table 77 Minimum, maximum, 5th, 50th and 95th percentiles of the contents of oxalate extractable Al, Fe and P content ($mmol_c\ kg^{-1}$) in the mineral soil

Statistic	Al_{ox} content			Fe_{ox} content			P_{ox} content		
	Loess	Clay	Peat	Loess	Clay	Peat	Loess	Clay	Peat
Minimum	36	78	17	27	108	7.9	0.26	0.51	0.22
5th percentile	77	111	31	77	194	21	0.73	1.5	0.28
50th percentile	156	204	122	154	440	69	4.1	8.1	1.5
95th percentile	278	329	416	304	888	773	16	28	13
Maximum	320	403	645	1 202	1 156	1 885	28	57	52

The topsoils of the three parent materials concerned here contain more Al_{ox} and Fe_{ox} than the topsoil (0-30 cm) of the sandy soils, which had median values for the Al_{ox} and Fe_{ox} contents of 110 and 31 $mmol_c\ kg^{-1}$, respectively (De Vries & Leeters, 1999). The P_{ox} contents of the peat soils are in the same range as those of the sandy soils (median value 1.7 $mmol_c\ kg^{-1}$; De Vries & Leeters, 1999). The loess and clay soils contain (much) more P_{ox} than the sandy soils.

The lowest P_{ox}/P_{tot} ratios occur in the peat soil. The median P_{ox}/P_{tot} ratio is slightly higher for the loess soils, compared to the clay soils, but for the clay soils the maximum is higher. The same pattern is found for the results on the $P_{ox}/(Al+Fe)_{ox}$ ratios. The maximum values of this ratio for the loess and clay soils almost equals the upper limit of the reversible bound amount of P_{ox} to Al_{ox} and Fe_{ox} (i.e. 0.2; Van der Zee et al., 1990a, 1990b; Breeuwsma & Schoumans, 1986). The P_{ox}/P_{tot} ratios are lower than those found for the sandy soils (median value 57%; De Vries & Leeters, 1999)). The median value for the $P_{ox}/(Al+Fe)_{ox}$ ratios are comparable with the median value for sandy soils (i.e. 0.03), but the maximum for sandy soils is much higher (i.e. 0.40) than the maximum values for loess and clay soils.

Table 78 Minimum, maximum, 5th, 50th, and 95th percentiles of the ratios of the oxalate extractable P contents in the mineral soil

Statistic	P_{ox} / P_{tot} (%)			P_{ox} / $(Al+Fe)_{ox}$ (mol mol^{-1})		
	Loess	Clay	Peat	Loess	Clay	Peat
Minimum	4.0	1.6	2.0	0.00	0.00	0.00
5th percentile	18	10	4.6	0.01	0.01	0.01
50th percentile	45	39	14	0.04	0.04	0.02
95th percentile	72	73	42	0.12	0.15	0.08
Maximum	81	100 [1)]	69	0.20	0.18	0.14

[1)] For 3 samples P_{ox}/P_{tot} ratios were found of more than 100%, with a maximum of 228%.

The pools of Al_{ox}, Fe_{ox} and P_{ox} in peat soils are considerably smaller that for the mineral soil types (Table 79). This difference is mainly related to the differences in bulk density, which even reinforced the already found differences in the contents of these elements. The values for the pools of Al_{ox} and the variation in these values are comparable for loess and clay soil. The values for the Fe_{ox} and P_{ox} pools, on the contrary, are almost twice as large for clay soils as those for loess soils. There is, however, still a considerable overlap between de distributions of these variables for the two soil types.

Table 79 Minimum, maximum, 5th, 50th and 95th percentiles of the total pools ($kmol_c$ ha^{-1} dm^{-1}) of oxalate extractable Al, Fe and P in the top 100 cm of the mineral soil

Statistic	Al_{ox} pool			Fe_{ox} pool			P_{ox} pool		
	Loess	Clay	Peat	Loess	Clay	Peat	Loess	Clay	Peat
Minimum	116	158	8.4	93	277	5.3	1.1	2.7	0.1
5th percentile	130	169	10	137	312	5.8	1.5	4.0	0.1
50th percentile	233	271	21	239	542	12	7.2	9.8	0.3
95th percentile	388	394	99	664	1 094	249	24	36	3.9
Maximum	399	395	114	1 428	1 410	293	26	63	5.2

5.3.2 Differences between the soil layers

The clearest trends with the depth occur in the peat soils, in which the contents of all three variable decrease with the depth, and for the P_{ox} contents, which decrease with depth in all three soil types (Table 80). The P_{ox}/P_{tot} and $P_{ox}/(Al+Fe)_{ox}$ ratios also decrease with the depth, but the values for the fourth layer are slightly higher than those for the third layer. A uniform decrease with depth is also found for the Fe_{ox} contents of the loess soils and the Al_{ox} contents of the clay soils. Down to a depth of 60 cm, also the Fe_{ox} contents of the clay soils decreases with the depth. However, the Al_{ox} contents of the loess soils show an increase for this depth.

The pools of Al_{ox}, Fe_{ox} and P_{ox} per layer in the loess and clay soils show an increase with the depth, but less than could be expected from the increase in thickness of the observed layers. For the peat soils, the increase in layer thickness is almost fully compensated by the decrease in P_{ox} contents.

Table 80 Median values (per soil layer) of the contents, pools and ratios of oxalate extractable Al, Fe and P in the mineral soil

Soil layer	Content ($mmol_c\ kg^{-1}$)			Pool ($kmol_c\ ha^{-1}\ dm^{-1}$)			P_{ox}/P_{tot} (%)	P_{ox} / $(Al+Fe)_{ox}$ ($mol\ mol^{-1}$)
	Al_{ox}	Fe_{ox}	P_{ox}	Al_{ox}	Fe_{ox}	P_{ox}		
Loess soils:								
0 - 10 cm	138	178	6.5	195	253	9.4	48	0.06
10 - 30 cm	163	169	4.0	238	245	6.3	45	0.04
30 - 60 cm	170	143	3.6	256	221	5.5	41	0.03
60 - 100 cm	159	143	3.2	243	220	5.0	43	0.03
Expl. variance (% R^2adj)	*0*	*22*	*46*	*2*	*11*	*41*	*19*	*31*
Clay soils:								
0 - 10 cm	224	473	11	284	552	13	56	0.05
10 - 30 cm	210	447	6.7	279	603	9.5	42	0.04
30 - 60 cm	209	392	5.1	271	514	6.8	29	0.02
60 - 100 cm	185	431	6.5	246	575	8.8	34	0.03
Expl. variance (% R^2adj)	*23*	*5*	*29*	*7*	*0*	*25*	*9*	*26*
Peat soils:								
0 - 10 cm	145	95	3.2	26	16	0.54	17	0.04
10 - 30 cm	124	62	1.5	22	10	0.28	15	0.02
30 - 60 cm	105	66	0.86	21	11	0.14	10	0.01
60 - 100 cm	92	56	0.77	14	9.1	0.12	11	0.02
Expl. variance (% R^2adj)	*6*	*22*	*60*	*4*	*17*	*55*	*52*	*59*

5.3.3 Relations with the environmental characteristics

Soil types

Within the loess soils, there is a negative correlation between the Al_{ox} contents and the Fe_{ox} and P_{ox} contents (Table 81). The highest Al_{ox} contents and the lowest Fe_{ox} and P_{ox} occur in the Cambisols in sandy loess. On the contrary, the lowest Al_{ox} contents and the highest Fe_{ox} and P_{ox} contents are found in the Fluvisols. For the clay soils the highest Al_{ox} occur in the fine-textured soil and highest Fe_{ox} and P_{ox} contents in the medium textured soils. The lowest values are found for the calcareous soils.

For the peat soils the highest Al_{ox}, Fe_{ox} and P_{ox} contents are found for the locations in the low moor area. Within the high moor area, the values are lowest for the Fibric Histosols. Comparable differences amongst the soil type clusters are found for the pools of these elements.

The $P_{ox}/(Al+Fe)_{ox}$ ratio generally increases in the line of the listed soil types for loess, whereas the P_{ox}/P_{tot} decreases in this order. This pattern is related to the slow increase in P_{ox} and the stronger increase in P_{tot}, which reflect the general fertility status of these soils. The highest ratios for the peat soils are found for the terric Histosol, which may have a better availability of P due to the better drainage conditions.

Table 81 Median values of the contents, pools and ratios of oxalate extractable Al, Fe and P in the mineral soil as a function of the soil type [1].

Soil type	Content (mmol$_c$ kg^{-1})			Pool (kmol$_c$ ha^{-1} dm^{-1})			P_{ox}/P_{tot} (%)	P_{ox} / $(Al+Fe)_{ox}$ (mol mol^{-1})
	Al_{ox}	Fe_{ox}	P_{ox}	Al_{ox}	Fe_{ox}	P_{ox}		
Loess soils:								
Cambisol in sandy loess	198	140	3.3	298	220	5.3	52	0.03
Cambisol in loamy loess	159	157	4.4	240	245	7.2	45	0.04
Haplic and Gleyic Luvisol	141	159	4.2	211	244	7.4	41	0.04
Eutric and Calcic Fluvisol	114	170	6.1	159	296	8.9	41	0.05
Expl. variance (% R^2adj)	*13*	*6*	*0*	*24*	*5*	*0*	*1*	*0*
Clay soils:								
Eut. Fluvisol, med.-texture	142	582	10.6	200	972	18	41	0.04
Eut. Fluvisol, fine-texture	250	438	7.7	315	538	8.7	34	0.03
Calcaric Fluvisol	144	312	6.8	206	441	10	37	0.05
Expl. variance (% R^2adj)	*56*	*0*	*0*	*52*	*9*	*0*	*0*	*0*
Peat soils:								
Fibric Histosol, high moor	90	57	0.69	16	9.2	0.1	9.6	0.02
Terric Histosol, high moor	129	60	1.9	22	12	0.5	18	0.03
Fibric Histosol, low moor	151	143	3.0	27	37	0.4	15	0.02
Expl. variance (% R^2adj)	*9*	*14*	*27*	*23*	*20*	*26*	*20*	*15*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

Statistical analysis

For the loess and peat soils, only weakly significant correlations were found between the variation in the Al_{ox} and Fe_{ox} variables and the predictors from the simple model and no significant model at al for the P variables (Table 82). For the clay soils, the variation in the Al_{ox} and Fe_{ox} variables is considerably stronger correlated with the soil type and the drainage class. Indications for a relationship with soil type are also found for the P_{ox} variable in the peat soils.

The extension of the model for the loess soils did not improve the results for the P_{ox} variables (Table 82). The resulting models for the Al_{ox} and Fe_{ox} variables also contain various deposition variables and the tree height. The inclusion of the deposition can be explained from the impact of the deposition on the depletion of the pools of these elements, but can also be related to differences in pH values. There is no good explanation for the inclusion of tree height, except for the correlation between tree height and the general site quality. The expansion of the model did not yield in any improvements for the P_{ox} variables.

Table 82 Best explaining environmental characteristics for the contents, pools and ratios of oxalate extractable Al, Fe and P in the mineral soil, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	$\%R^2_{adj}$	Sign.[3]	Factors	$\%R^2_{adj}$	Sign.[3]
Loess soils:						
Al_{ox} content	So	13	*	Di + Dp_{no} + He	51	***
Fe_{ox} content	So + Dr	20	*	Dr + Dp_{nh}.Dr + He + Di	65	***
P_{ox} content	-	0	-	-	0	-
Al_{ox} pool	So	24	**	Di + Dp_{no} + He + Tr	66	***
Fe_{ox} pool	So + Dr	27	**	Dr + Dp_{nh}.Dr + Di	60	***
P_{ox} pool	-	0	-	-	0	-
P_{ox}/P_{tot} ratio	So	1	-	-	0	-
$P_{ox}/(Al+Fe)_{ox}$ ratio	Dr	1	-	-	0	-
Clay soils:						
Al_{ox} content	So + Dr	65	***	So + Dr + Di	70	***
Fe_{ox} content	So + Dr_c	29	**	So + Dr_c	29	**
P_{ox} content	-	0	-	He	19	*
Al_{ox} pool	So + Dr	59	***	So + Dr + Di	65	***
Fe_{ox} pool	So + Dr_c	28	**	So + Dr_c + He + La	45	**
P_{ox} pool	-	0	-	He	19	**
P_{ox}/P_{tot} ratio	-	0	-	He	15	*
$P_{ox}/(Al+Fe)_{ox}$ ratio	Dr_c	3	-	Dp_{so}.Dr_c	15	*
Peat soils:						
Al_{ox} content	So + Dr	9	-	Dp_{so} + Ds	38	****
Fe_{ox} content	So + Dr_c	27	*	Dr_c + Dp_{no}	35	**
P_{ox} content	So	27	**	Dp_{no}	53	***
Al_{ox} pool	So + Dr	30	*	Dp_{so}	42	***
Fe_{ox} pool	So + Dr_c	32	*	So + Dr_c	32	**
P_{ox} pool	So	26	**	Dp_{no}	48	***
P_{ox}/P_{tot} ratio	So	20	*	So + Dp_{no}	44	***
$P_{ox}/(Al+Fe)_{ox}$ ratio	So + Dr_c	17	*	So + Tr + Ca + Dr_c + Dp_{no}	58	**

1) Simple model: analysis only with 'Soil Type' and 'Drainage Class (coding cf. Section 2.4).
2) Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).
3) Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

There are hardly any differences in the extended and simple model for the clay soils (Table 82). The direction of the forest edge appears for the Al_{ox} and Fe_{ox} variables, whereas the tree height is selected for the P_{ox} variables. The latter result may be related to the correlation between the P availability and the general growth condition at the site, which allow a better growth.

Extension of the model results for most Al_{ox}, Fe_{ox} and P_{ox} variables in the selection of a deposition variable (mostly NO_x or SO_x) and for the $P_{ox}/(Al+Fe)_{ox}$ ratio also in the selection of the tree species and the canopy coverage (Table 82). It was not possible to find a good explanation for this result.

5.4 Total mineral contents

5.4.1 Major elements

The analysis of the total contents of the major elements include the results for Si, Al, Ca, Mg, K, Na, Fe, Mn and Ti. These elements have been analysed in all four layers of a selection of 10 profiles in both loess and clay soils. A selection of these elements (Al, Ca, Mg, K and Fe) have also been determined in the topsoils (0-10 cm) of all 30 peat soils. The comparability of these results with the results for the loess and peat soils is not only limited by the different selection of a subset of samples, but probably also by the different destruction methods applied for loess and clay soils vs. the peat soils (which have been treated as humus samples; see Section 2.3.3). The evaluation is focused on the overall variation in all three soil types, followed by the differences between the soil layers in the loess and peat soil (all layers have been analysed in the considered subsets of locations) and finally the relationship with the environmental characteristics is investigated for the peat soils (all locations have been analysed for the one selected layer).

5.4.1.1 Overall variation

Silicium (Si) is the most important element in both loess and clay soils (Table 83), which is in line with the expectations, since Si is the most important element in sand minerals and also a main element of clay minerals. This element has not been determined in peat soils, since peat soils mainly consist of organic matter, whereas Si is a part of mineral part of the soil. If Si would have been determined in the peat soils, it would have clearly correlated with the fraction of mineral material. The distribution of the results would therefore be almost exactly opposite to the organic matter content. This pattern could also be recognized in the Al content of the peat soils.

Second and third element in both loess and clay soils are Al and Fe, respectively (Table 83). Both element show considerable variation in both soil types, but the values are generally higher in the clay soils. This is probably related to the higher content of clay mineral and other 'rich' minerals in the clay soils, compared to the loess soils. The loess soils probably have a higher content of nutrient poor sand minerals. A similar difference, but on different levels, between loess and clay soils was found for Ca, Mg Fe and Mn. The variation in Na and Ti was similar for both soil types, whereas for K the difference was intermediate.

The variation in the contents of Ca, Mg, K and Fe in the peat soils occurs generally on a clearly lower level than in the loess and peat soils (Table 83). This is not only related to the different extraction methods, but primarily with the difference in origin of the material. Most of these elements origin from plant material. In some locations also the admixture of mineral particles plays a role and in some other locations the influence of the mineral content of seepage water or near-by surface water may also play a role.

Table 83 Minimum, maximum, 5th, 50th and 95th percentiles of the total contents (g kg^{-1}) of the major minerals in the mineral topsoil

Statistic	Si	Al	Ca	Mg	K	Na	Fe	Mn	Ti
Loess soils [1]:									
Minimum	297	18	1.1	0.73	2.0	2.7	3.9	0.06	0.36
5th percentile	345	22	1.2	0.85	4.7	3.5	7.4	0.11	0.91
50th percentile	382	33	1.9	1.7	14	6.1	11	0.36	2.1
95th percentile	410	48	4.2	4.2	18	7.4	27	0.83	2.8
Maximum	415	49	4.4	4.4	19	7.5	30	1.0	2.8
Clay soils [1]:									
Minimum	236	29	0.29	2.2	9.5	3.3	19	0.29	0.72
5th percentile	244	32	1.1	2.6	10	3.5	20	0.40	0.81
50th percentile	311	62	3.7	6.2	17	4.8	35	0.78	2.0
95th percentile	371	90	9.4	11	21	6.5	58	1.4	2.8
Maximum	386	94	19	12	22	6.9	84	1.8	3.0
Peat soils [2]:									
Minimum		0.97	0.92	0.33	0.24		1.6		
5th percentile		0.98	1.1	0.36	0.27		1.8		
50th percentile		3.1	1.6	0.54	0.57		3.5		
95th percentile		26	6.2	2.4	4.4		24		
Maximum		26	18	2.6	4.4		35		

1) Based on values from 10 plots, from which all layers were analyzed (40 values in total).

2) Based on the values from all 30 plots, from which only the topsoil was analyzed (30 values in total).

5.4.1.2 Differences between the soil layers

The differences between the soil layers could only be analysed for the loess and clay soil (both on a selection of 10 plots). For the peat soils only the top 10 cm (of all location) had been sampled. The figures in Table 83 already presented results for this layer.

The total contents of most of the considered element show a clear increase with depth in the loess soils (Table 84). This is an indication that a considerable depletion of these element has taken place in the last centuries and millennia, due to weathering of the available minerals, when we assume that the profiles originally had a more or less homogeneous mineral composition. The clay soils also show in increase with depth for at least some of the elements, but for the most important elements (e.g. Ca) the level of the results is still much higher. This indicates that even in clay soils weathering is an important process of loss of minerals, but that there are still considerable pools of these elements left over.

Table 84 Median values (per soil layer) of the total contents (g kg⁻¹) of the major minerals in the mineral topsoil of the loess and clay soils[1)]

Soil layer	Si	Al	Ca	Mg	K	Na	Fe	Mn	Ti
Loess soils:									
0 - 10 cm	360	28	1.8	1.4	12	5.5	10	0.19	1.9
10 - 30 cm	384	31	1.9	1.4	13	6.1	11	0.29	1.8
30 - 60 cm	390	33	2.0	1.7	14	6.3	12	0.40	2.2
60 - 100 cm	388	35	2.0	2.1	15	6.3	17	0.49	2.3
Expl. variance (% R^2adj)	*24*	*66*	*3*	*58*	*21*	*4*	*34*	*40*	*13*
Clay soils:									
0 - 10 cm	312	52	3.2	5.3	16	4.8	33	0.72	1.8
10 - 30 cm	316	57	3.1	5.8	17	4.8	31	0.86	1.9
30 - 60 cm	308	68	4.2	7.4	19	4.6	34	0.75	2.3
60 - 100 cm	306	66	4.4	7.2	18	5.0	36	0.86	2.3
Expl. variance (% R^2adj)	*0*	*60*	*28*	*64*	*37*	*8*	*27*	*19*	*45*

[1)] The data for the peat soils were already limited to one layer (the topsoil, 0 - 10 cm).

5.4.2.3 Relations with the environmental characteristics

Soil types

The comparison of the results between the various soil types has only been carried out for the peat soil, since all locations on peat had been include in the assessment, whereas for the loess and clay soil only 10 plots had been included. The results for the peat soils show that the highest Al and Fe (and Ca) contents were found in the 'Terric' soils (Table 85), which confirms the knowledge about the larger admixture of mineral particles in the soil type. The highest Mg and K (and Ca) contents were found in the plots in the low moor area. This confirms the idea that these peat soils have been formed under mineralogically richer condition and/or that the level of nutrient cycling is presently higher than in the peat soils in the high moor area.

Table 85 Median values of the total contents (g kg⁻¹) of the major minerals in the mineral topsoil of the peat soils as a function of the soil type [1)].

Soil type [2)]	Si	Al	Ca	Mg	K	Na	Fe	Mn	Ti
Peat soils:									
Fibric Histosol, high moor		3.1	1.2	0.45	0.45		3.0		
Terr. Histosol, high moor		4.1	1.7	0.48	0.59		7.4		
Fibric Histosol, low moor		2.0	1.7	0.94	1.0		3.3		
Expl. variance (% R^2adj)		*0*	*0*	*47*	*42*		*5*		

[1)] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.
[2)] The data for the loess and clay soils were limited to only 10 plots.

Statistical analysis

The variation in the total contents of Al, Ca and Fe in the peat soils can, within the simple model, hardly or only non-significantly be explained by the available environmental characteristics (Table 90). The variation in the total contents of Mg and K could statistically significantly be explained by the soil type, combined with the drainage class. The possible extension of the model with all other environmental factors did not result in an improvement for the Al contents. The variation in the total contents of most elements appears to be strongly positively correlated with the deposition of NO_x. This probably an artefact related to the coincidence of high NO_x deposition and strong influence of near-by surface water (possibly combined with spreading of sediment into the forest).

Table 86 Best explaining environmental characteristics for the total contents of the major minerals in the mineral topsoil of the peat soils [1], retrieved by multiple regression analysis

Analysed variable	Simple model [2]			Full model [3]		
	Factors	$\%R^2_{adj}$	Sign.[4]	Factors	$\%R^2_{adj}$	Sign.[4]
Peat soils:						
Si						
Al	-	0	-	-	0	-
Ca	So + Dr	12	-	Dr + Dp_{no}.So + La2	56	**
Mg	So + Dr	49	***	So + Dp_{no}	59	***
K	So	42	***	So + Dp_{no}	55	***
Na						
Fe	So	5	-	Dp_{no}	31	***
Mn						
Ti						

1) The data for the loess and clay soils were limited to only 10 plots.
2) Simple model: analysis only with 'Soil Type' and 'Drainage Class' (coding cf. Section 2.4).
3) Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).
4) Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

5.4.2 Heavy metals

The assessment of heavy metals has been limited to the topsoil of included locations. So no analysis of the differences between the various soil layers could be made.

5.4.2.1 Overall variation

The contents of heavy metals in the topsoil (0-10 cm) of the loess, clay and peat soil vary considerably, although most result were around the considered background level or slightly above that level (Tables 87 and 88). The highest (median) values for the Pb and Cd contents were found in the topsoils in peat, whereas the highest values for the Cu, Zn, Ni and Cr were found for the clays soils. On the other hand, the peat soils show the lowest values for the Ni and Cr content , whereas the clays soils show the lowest median Pb contents. the loess soils show the lowest median contents of Cd, Cu and Zn. There was, however, also much overlap in the ranges of every single heavy metal, when comparing the three soil types. The numbers of plots in the classes with 'elevated' heavy metal contents reflects the pattern of high heavy metal contents (Table 88 vs. 87). The result for the peat soils were generally classified more positively, since the critical heavy metal contents are strongly related with the organic mater contents.

Table 87 Minimum, maximum, 5th, 50th and 95th percentiles of the heavy metal contents ($mg\ kg^{-1}$) in the mineral topsoil

Statistic	Pb	Cd	Cu	Zn	Ni	Cr
Loess soils:						
Minimum	25	0.00	4.2	15	3.4	32
5th percentile	30	0.00	5.1	18	3.9	33
50th percentile	66	0.00	9.7	45	9.2	52
95th percentile	139	0.92	18	128	20	67
Maximum	159	1.3	22	211	25	71
Clay soils:						
Minimum	25	0.07	5.9	33	12	30
5th percentile	32	0.12	9.9	52	13	32
50th percentile	58	0.33	25	125	39	77
95th percentile	167	1.6	35	351	53	100
Maximum	252	6.3	103	703	55	108
Peat soils:						
Minimum	9.4	0.15	4.9	16	3.9	4.3
5th percentile	50	0.44	6.8	33	4.8	4.7
50th percentile	106	0.97	13	64	7.3	9.9
95th percentile	291	3.3	47	191	18	40
Maximum	308	3.6	85	221	24	89

Table 88 Distribution (in number of plots) of the heavy metal contents of the mineral topsoil over the soil pollution classes for heavy metals, according to the Dutch criteria for soil pollution

Pollution class	Pb	Cd	Cu	Zn	Ni	Cr
Loess soils:						
< Target Value	23	35	40	36	39	40
> Target Value	17	5	0	4	1	0
> Examination Value	0	0	0	0	0	0
> Intervention Value	0	0	0	0	0	0
Clay soils:						
< Target Value	17	24	13	3	0	5
> Target Value	13	6	16	25	24	25
> Examination Value	0	0	1	1	6	0
> Intervention Value	0	0	0	1	0	0
Peat soils:						
< Target Value	20	24	29	29	30	29
> Target Value	10	6	1	1	0	1
> Examination Value	0	0	0	0	0	0
> Intervention Value	0	0	0	0	0	0

The differences between the soil types were generally in line with the differences between the heavy metal contents of the humus layers on loess and peat soils (see Section 4.3). The results for Pb, Cd, Cu and Zn were generally equal or lower than the corresponding results in the humus layer, whereas the results for Ni and Cr were generally higher than in the humus layer. This indicates that the former four may mainly yield from atmospheric deposition, whereas the latter two may predominantly related to soil characteristics or a different source of soil pollution.

5.4.2.2 Relations with the environmental characteristics

Soil types

The highest values for most of the heavy metals within the loess soils occur for the Fluvisols (except Pb and Cr; Table 89). The results for this class are probably typical for fluvial clay soils, since similar values were found for the 'real' clay soils (except for the Cr content). The Cambisols in sandy loess loam show the lowest heavy metal contents within the loess soils, except for Cr, for which it shows almost the highest value. The low values are probably related to the low natural background values of these rather sandy soils.

Within the clay soils, the highest values for Pb and Cd were found for the medium-textured Eutric Fluvisols, whereas the highest values for the other four heavy metals were found for the fine-textured soils (Table 89). The calcareous soils always show intermediate results.

Table 89 Median values of the heavy metal contents (mg kg^{-1}) in the mineral topsoil as a function of the soil type[1)]*.*

Soil type	Pb	Cd	Cu	Zn	Ni	Cr
Loess soils:						
Cambisol in sandy loess	45	0.00	6.5	2.4	7.4	36
Cambisol in loamy loess	83	0.00	10	4.8	9.3	51
Haplic and Gleyic Luvisol	63	0.05	9.4	3.8	11	5.4
Eutric and Calc. Fluvisol	58	0.45	13	103	14	5.6
Expl. variance (% R^2adj)	*1*	*3*	*13*	*24*	*9*	*22*
Clay soils:						
Eutr. Fluvisol, med. texture	60	0.48	19	98	29	63
Eutr. Fluvisol, fine texture	57	0.32	26	132	40	84
Calcic Fluvisol	39	0.22	21	96	36	67
Expl. variance (% R^2adj)	*9*	*2*	*0*	*0*	*20*	*20*
Peat soils:						
Fibr. Histosol, high moor	107	1.7	11	70	5.8	8.7
Terr. Histosol, high moor	144	1.2	16	98	8.3	12
Fibric Histosol, low moor	93	0.65	13	49	7.9	8.5
Expl. variance (% R^2adj)	*0*	*25*	*2*	*11*	*14*	*0*

1) Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

The highest heavy metal contents within the peat soils are found for the terric Histosols in the high moor area (except for the Cd contents). This pattern is probably related with (i) the coincidence of the distribution of these soil types with spatial distribution of the heavy metal deposition, (ii) the chemical composition of the admixture of mineral particles and (iii) the concentrating effect of the earthifying process which has taken place in these soils.

Statistical analysis
Statistical analysis of the results shows that for most heavy metals the variation in the topsoils can not or only weakly be explained by soil type and/or drainage class (i.e. the 'simple model'). Reasonable to good correlations, however, are found for the Cr content in loess and clay soils and the Ni content of clay soils. The variation in these metals is probably related with the clay content of the soils, which is a function of the distinguished soil types, and partly also of the drainage class.

Table 90 Best explaining environmental characteristics for the heavy metal contents in the mineral topsoil, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	$\%R^2_{adj}$	Sign.[3]	Factors	$\%R^2_{adj}$	Sign.[3]
Loess soils:						
Pb	So	1	-	-	0	-
Cd	So	1	-	-	0	-
Cu	So	13	*	Dp_{no}	20	**
Zn	So + Dr	24	**	So + Dp_{so}	45	***
Ni	So + Dr	11	*	Dp_n	25	***
Cr	So + Dr	37	***	So + Dr + Dp_{no}	53	***
Clay soils:						
Pb	So + Dr_c	11	-	So + Dp_{no}.So	46	**
Cd	So + Dr_c	15	*	Tr + Dp_n.So + So	66	***
Cu	Dr_c	16	*	Dr_c + Di	32	**
Zn	Dr_c	16	*	Dr_c + Di	31	**
Ni	So + Dr_c	46	***	So+Dr_c+Di+Dp_{nh}+Dp_{nh}.So	72	***
Cr	So + Dr_c	33	**	So + Dr_c + Di + Dp_{nh}	54	***
Peat soils:						
Pb	Dr_c	0.4	-	-	0	-
Cd	So + Dr_c	31	**	So + Dr_c	31	**
Cu	Dr_c	6	-	Dr_c	6	-
Zn	So	11	*	So	11	*
Ni	So	14	*	Dp_{no}	34	***
Cr	Dr_x	6	-	Dr_c	6	-

[1] Simple model: analysis only with 'Soil Type' and 'Drainage Class' (coding cf. Section 2.4).
[2] Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).
[3] Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

The contents of Cu, Zn, Ni and Cr in the loess soils seem to correlate best with one of the deposition terms. These terms are also added in the extended model for most heavy metals in the clay soils and the Ni content in the peat soils. This result is hard to explain, since there is no clear relationship between the deposition these substances and (i) the deposition of these heavy metals or (ii) the accumulation of these metals. The deposition of Ni and Cr is generally even considered neglectible, compared to other source of these metals. The only correlation between the deposition of heavy metals and acidity is related to edge effects. The (dry) deposition of both groups of substances is higher in exposed forest edges, and at different levels of canopy roughness. This could also be the reason for the inclusion of stand characteristics, such as tree species and direction of the forest edge.

5.5 Summary and conclusions

The following summarizing conclusions can be drawn from the preceding sections:

1. The **organic matter contents** of the mineral parent materials increase from (sandy soils) < loess soils < clay soils. The organic matter contents decrease with depth for the loess and clay soils. The organic matter content of the peat soils is mostly above 900 g kg^{-1}, with somewhat lower values for the topsoils of the Terric Histosols and the lower layers in the low moor peat soils.

2. The bulk density increases with depth for the loess soils, had a maximum in the layer 10-30 cm for the clay soil and was stable with depth for the peat soils.

3. In general an increase is found for the **N and P contents** (of the organic matter) and P pools: peat soils < (sandy soils) < loess soils < clay soils and a decrease in C/N in this order. The N contents and pools and the C/N ratio decrease with depth for all soil types. The N contents and C/N ratios are well correlated with the deposition levels for the loess and clay soils and with the soil type for the peat soils.

4. The **pH values** increase from peat soils (+ sandy soils) < loess soils < clay soils. In general the pH values increase with the depth. Most clay soils and the Fluvial loess soils are in the upper end of the cation exchange buffer range. Most loess soils are at the lower end of the cation exchange buffer range. The pH values increase with depth for the loess and peat soil and decrease for the clay soils. Difference between the locations are correlated with the soil type for all three parent materials and with the deposition level for the loess soils.

5. The **CEC** of the peat soils is almost completely determined by the organic matter content (and the pH), whereas the CEC for the loess and clay soils is determined by the clay and organic matter contents. The CEC of the clay is considerably less effective for loess soils than for 'regular' clay soils.

6. The **base saturation** decreases from clay soils > peat soils > loess soils > sandy soils. The Fluvial loess soils and the low moor peat soils have a considerably higher base saturation the rest of these soils, because of the fluvial character and the influence of mesotrophic surface water, respectively. For the peat soils, H has a relatively large share in the acid cations, due to the absence of mineral particles. For the clay and peat soils, the base saturation increases with depth. The Fluvial loess soils have similar base saturation as the clay soils. Within the peat soil the base saturation increases with the expected decrease in vulnerability to acidification. Within the loess soils, the base saturation and H occupation are also correlated with the deposition levels.

7. The **Al_{ox}, Fe_{ox} and P_{ox} contents** decrease from clay soils > loess soil > peat soil > (sandy soils) and, generally decrease with depth. The pools for peat soils are, however, much smaller than for sandy soil. Within the three groups, contents and pools generally increase with the expected decrease in vulnerability to acidification.

8. The **total contents of minerals and heavy metals** are generally related to the soil type, especially as expressed in the differences in clay content. The heavy metal content is generally slightly elevated for Pb (all soil types) and for Cu, Zn, Ni and Cr (in the clay soils). A relationship with atmospheric deposition can not be proven. No seriously polluted sites were found.

6 Chemical composition of the soil solution

In this chapter we give an overview of the chemical composition of the soil solution, subdivided in the following aspects: pH, nutrient concentrations and nutrient ratios. First the variation in the observed or calculated data is given (Section 6.1), then the influence of the depth on a selection of these variables (Section 6.2) and finally the influence of the deposition and of the stand and site characteristics is discussed (Section 6.3). The comparison with the results for the sandy soils (De Vries & Leeters, 1999) can be found in Section 6.2, since the results for the sandy soils are only available per layer.

6.1 General overview

6.1.1 pH and nutrient concentrations

The lowest values for the pH in the soil solution are found for the peat soils, with a median value of 3.7 (Table 91). The values for the loess soils are 0.3 to 0.4 unit higher. The values for the clay soils are much higher, with a median value of 6.3. Approximately the same patterns for the pH(H_2O) and the pH(KCl) of the mineral soil were found for the three parent materials (Section 5.2).

The loess soils have the lowest median values for the Mg, Na and Fe concentrations and the highest median values for the K, Al, Mn, NO_3 and SO_4 concentrations (Table 91). The clay soils have the lowest median values for the K, Al, Fe, Mn and NH_4 concentrations and the highest median values for the Si and Ca concentrations. The peat soils have the lowest median values for the Si, Ca, Mn, NO_3 and SO_4 concentrations and the highest median values for the Mg, Na, Fe, NH_4, Cl, H_2PO_4 and RCOO concentrations.

Median values of 0 or almost 0 are found for the H_2PO_4 concentration in loess soils, for the NH_4, H_2PO_4 and Mn concentrations in the clay soils and for the Mn concentration in the peat soil and for the NH_4 concentration in the clay soils (Table 91). Extremely high maximum values are found for the Ca and NO_3 concentrations in the loess soils and for the Ca, Mg, Na and Cl concentrations in the peat soils. The observed maximum values for the NO_3 concentration in peat soils can be considered as remarkably high, since peat soils, in general, are characterized by very nutrient poor conditions. The maximum value for the pH in the peat soils, in combination with the maximum Ca and Mg concentrations, indicates that some locations are affected by base rich seepage water.

Table 91 Minimum, maximum, 5th, 50th and 95th percentiles of the pH and the nutrient concentrations in the soil solution

Statistic	pH	Concentrations (mol_c m^{-3})													
		Si	Ca	Mg	K	Na	Al	Fe	Mn	NH_4	NO_3	SO_4	Cl	H_2PO_4	RCOO
Loess soils: [1]															
Minimum	3.3	0.38	0.22	0.00	0.08	0.01	0.00	0.00	0.00	0.01	0.00	0.31	0.06	0.00	0.04
5th percentile	3.6	0.55	0.25	0.08	0.09	0.02	0.03	0.00	0.00	0.02	0.07	0.38	0.15	0.00	0.09
50th percentile	4.1	1.3	0.81	0.23	0.17	0.26	0.28	0.02	0.04	0.05	0.99	0.83	0.31	0.00	0.19
95th percentile	6.5	2.7	4.1	0.65	0.51	0.91	1.5	0.14	0.17	0.28	2.6	2.7	1.2	0.02	0.38
Maximum	7.6	3.1	16	1.8	0.74	1.5	3.1	0.62	0.29	1.7	9.0	6.7	2.1	0.05	0.57
Clay soils:															
Minimum	3.9	0.51	0.21	0.05	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	-
5th percentile	4.4	0.73	0.27	0.10	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.25	0.06	0.00	-
50th percentile	6.3	1.6	1.2	0.27	0.01	0.47	0.02	0.02	0.00	0.00	0.13	0.68	0.20	0.00	-
95th percentile	7.6	3.4	2.9	0.57	0.10	1.6	0.27	0.13	0.05	0.05	0.56	2.2	1.1	0.05	-
Maximum	8.3	4.0	5.7	0.92	0.16	3.2	0.76	0.32	0.16	0.19	1.1	6.8	3.1	0.19	-
Peat soils:															
Minimum	3.0	0.10	0.06	0.05	0.00	0.19	0.00	0.00	0.00	0.02	0.00	0.11	0.37	0.00	0.09
5th percentile	3.2	0.17	0.12	0.09	0.02	0.26	0.01	0.01	0.00	0.06	0.00	0.19	0.44	0.00	0.15
50th percentile	3.7	0.46	0.44	0.29	0.08	0.55	0.08	0.03	0.00	0.23	0.09	0.67	0.89	0.03	0.24
95th percentile	6.1	1.8	3.0	1.6	0.34	2.7	0.20	0.12	0.04	0.79	1.8	2.2	3.6	0.16	0.39
Maximum	7.3	2.6	8.0	4.0	1.9	8.8	0.26	0.23	0.17	1.3	6.0	4.8	17	0.33	0.49

[1] Data for loess soils based on layers 0-10 cm, 10-30 cm and 60-100 cm only.

The maximum values for the Na and Cl concentrations in the peat soils indicate that there are also locations that are affected by seepage of brackish ground water.The general pattern of the differences between the three parent materials indicate, that the loess soil are affected most by atmospheric deposition. The high concentrations of NO_3 and SO_4 reflect the high deposition of S and N (and acidity) on these locations. These inputs are mainly buffered by K and Al (and Mn).

The results for the clay soils show, that the majority of the locations do not show significant traces of acidification. For these soils all atmospheric input and internal production of acidity is easily buffered by the release of Ca and Si at high pH values. At some locations even the carbonate buffer is still active. Only a few locations have a lower pH and significant concentrations of Al and NH_4. Furthermore, the low K concentrations in the clay soils may be due to K fixation, which may play an important role in these soils.

Since the weathering of mineral compounds does not play an important role in peat soils, the buffering by cation exchange is the major buffering mechanism in these soils. For the peat soils NH_4 seems to be the most important compound from atmospheric deposition. However, the NH_4 concentrations may also remain relatively high, due to hampered nitrification under wet conditions. The inhibited nitrification, combined with an enhanced denitrification, may also cause the low NO_3 at several locations.

6.1.2 Nutrient ratios

The general overview of the element ratios in the soil solution (Table 92) contains four ratios related to effects of the input of N and acidity: NH_4/NO_3, NH_4/K, NH_4/Mg and Al/Ca. Except for the first ratio, critical levels have been determined for these ratios. Values above these levels are supposed to adverse effects on plant growth. The critical levels for the NH_4/K and NH_4/Mg are 5.0 and 10.0 $mol_c\ mol_c^{-1}$, respectively. The critical level for the Al/Ca is 1.0 $mol\ mol^{-1}$. The other two ratios, $(NH_4+NO_3)/SO_4$ and $(H+Al)/(NO_3+SO_4-NH_4)$, characterise the main active processes. The former gives the balance between N and S in the acidification. The latter gives information on the mobilization of acid cations due to leaching of S and N compounds.

Within this survey, the loess soils have the highest median values for the Al/Ca and $(NH_4+NO_3)/SO_4$ ratios. The critical Al/Ca level is exceeded for a significant number of loess locations. Besides, some samples show an exceedance of the critical NH_4/Mg level. The high values for the Al/Ca ratio indicate that Al release plays an important role in the buffering of acidity in the loess soils. N containing compounds are the main source of acidification on most locations, but nitrification is still strong enough to keep the NH_4 ratios below the critical values.

The lowest median values for all the calculated ratios are found for the clay soils. The lower ranges of the ratios show many values that are 0 or almost 0. This indicates that (the majority of) the locations on clay soils are not affected by the input of N and acidity. The acid input is fully buffered by base cations and the NH_4 input is quickly nitrified or taken up by the trees and the ground vegetation. The values in the upper range of the NH_4/NO_3, NH_4/K and the Al/Ca ratios show, however, that some locations are clearly affected. Especially the NH_4/K ratio shows exceedances of the critical level of 5 $mol_c\ mol_c^{-1}$.

The highest median values for the NH_4/NO_3, NH_4/K and NH_4/Mg ratios are found for the peat soils. These results indicate a strongly hampered nitrification (and possibly an enhanced denitrification), due to the poor and very wet conditions in most of these soils. Most ratios show the consequences of a very high NH_4 concentration, combined with low concentrations of other elements. The maximum values of the NH_4/NO_3 and NH_4/K ratios are extremely high. The $(H+Al)/(NO_3+SO_4-NH_4)$ ratio shows a very wide range, with rather extreme negative values. These negative values reflect a composition of the soil solution in which the NH_4 concentration is higher than the sum of the NO_3 and SO_4 concentrations. However, also the highest $(H+Al)/(NO_3+SO_4-NH_4)$ ratios are found in the peat soils.

Table 92 Minimum, maximum, 5th, 50th and 95th percentiles of a wide selection of nutrient ratios in the soil solution

Statistic	Ratio ($mol_c\ mol_c^{-1}$)						
	$\frac{NH_4}{NO_3}$	$\frac{NH_4}{K}$	$\frac{NH_4}{Mg}$	$\frac{Al}{Ca}$ [2]	$\frac{Al}{B.C.^{1)}}$ [2]	$\frac{NH_4+NO_3}{SO_4}$	$\frac{H-Al}{NO_3+SO_4-NH_4}$
Loess soils: [3]							
Minimum	0.00	0.02	0.01	0.00	0.00	0.02	0.00
5th percentile	0.01	0.07	0.04	0.00	0.00	0.11	0.01
50th percentile	0.07	0.31	0.24	0.30	0.08	1.5	0.26
95th percentile	0.70	1.9	1.6	1.7	0.48	2.7	0.68
Maximum	3.3	4.0	8.1	3.2	0.62	3.7	0.81
Clay soils:							
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5th percentile	0.00	0.00	0.00	0.00	0.00	0.01	0.00
50th percentile	0.01	0.11	0.01	0.01	0.01	0.27	0.03
95th percentile	2.9	6.5	0.19	0.59	0.13	0.74	0.61
Maximum	28	44	0.85	0.90	0.40	1.4	1.7
Peat soils:							
Minimum	0.01	0.10	0.02	0.00	0.00	0.07	-13
5th percentile	0.03	0.31	0.08	0.01	0.00	0.12	-0.83
50th percentile	2.2	3.4	0.85	0.10	0.02	0.77	0.42
95th percentile	75	14	3.7	0.38	0.07	2.6	2.4
Maximum	119	129	7.6	0.53	0.10	4.5	5.2

[1] B.C. = Ca+Mg+K+Na
[2] Al/Ca and Al/B.C. ratios in mol mol^{-1}.
[2] Data for loess soils based on layers 0-10 cm, 10-30 cm and 60-100 cm only.

6.2 Differences between the soil layers

The pH of the soil solution increases significantly with depth for all three parent materials (Table 93). The increase is smallest for the peat soils (0.2 unit) and largest for the clay soils (1.2 units). The median value for the pH in the subsoil of the clay soils shows that a considerable number of these soils has a subsoil that is still in the carbonate buffer range, either by the presence of original carbonate or by the influx of carbonate and base rich seepage water.

The Ca and SO_4 concentrations increase with depth for all three parent materials, whereas the Al and NO_3 concentrations decrease (Table 93). The large decrease in NO_3 concentration with depth in clay and peat soils most probably reflects the effect of enhanced denitrification with depth. The K concentrations increase with depth for the loess soils but decrease with the depth for the clay and peat soils. The NH_4 concentrations decrease with the depth for the loess and clay soils, but stay relatively constant in the peat soils, thus reflecting limited nitrification.

The overall pattern for the ratios is a decrease with depth for all three presented ratios, except for the NH_4 related ratios in the peat soils (Table 93). Both the NH_4/NO_3 and the NH_4/K ratio show a very strong increase with the depth. Together with the pattern for the concentrations of the separate elements, this pattern again indicates that the nitrification is strongly hampered and that the denitrification might be enhanced with the depth.

The pH values in the peat soils are closest to the values found for the sandy soils, both for the topsoil and the subsoil (De Vries & Leeters, 1999). The pH values for the loess soils and especially for the clay soils are significantly higher. The trends with depth found in this survey are comparable to those for the sandy soils, except for the Ca concentration, which decreased with depth in the sandy soil.

The levels found for the concentrations in the three parent materials observed in this survey are generally different from the ones found for the sandy soils. The Al concentrations in all the three parent materials observed in this survey are lower than the values found for sandy soils. For the other elements the values for sandy soils were within the range of values observed here.

In the loess soils the Ca and NO_3 concentrations are higher than the ones found for the sandy soils, the Al and NH_4 concentrations are lower and the K and SO_4 concentrations are comparable. This reflects that loess soils are less acidified (lower Al concentrations) than sandy soils, whereas the leaching rates of SO_4 and NO_3 are comparable. In the clay soils only the Ca concentrations in the subsoil are higher than in the sandy soils, the concentrations of the other elements are lower. In the peat soils the K, Al, NO_3 and SO_4 are lower than in the sandy soils, the NH_4 concentrations are higher.

The values found in this survey for the NH_4/NO_3 ratio, the NH_4/K ratio and the Al/Ca ratio in the loess and clay soils are (much) lower than the values found for the sandy soils (De Vries & Leeters, 1999). Like for the loess and clay soils, the NH_4/NO_3 ratio and the NH_4 ratio in the sandy soils decrease with the depth, but, unlike the results found here, the Al/Ca ratio in the sandy soils increases with the depth. The ratios for the peat soils contrast strongly with the results for the sandy soils, especially the NH_4/NO_3 ratio and the NH_4/K ratio. These two ratios are much higher here, and they clearly increase with depth.

Table 93 Median values (per soil layer) of the pH and the nutrient concentrations and ratios in the soil solution

Soil layer	pH	Concentrations ($mol_c\ m^{-3}$)						Ratios ($mol\ mol^{-1}$)		
		Ca	K	Al	NH_4	NO_3	SO_4	NH_4/NO_3	NH_4/K	Al/Ca
Loess soils:										
0 - 10 cm	3.9	0.79	0.14	0.28	0.08	1.1	0.70	0.08	0.63	0.28
10 - 30 cm	4.1	0.62	0.15	0.33	0.05	1.1	0.81	0.06	0.29	0.39
30 - 60 cm	-	-	-	-	-	-	-	-	-	-
60 - 100 cm	4.3	1.1	0.26	0.18	0.04	0.72	1.3	0.05	0.13	0.15
Expl. variance (% R^2adj)	*41*	*17*	*54*	*7*	*15*	*0*	*29*	*5*	*26*	*11*
Clay soils:										
0 - 10 cm	5.7	1.5	0.03	0.08	0.01	0.31	0.73	0.03	0.21	0.03
10 - 30 cm	6.1	1.1	0.01	0.04	0.00	0.15	0.55	0.01	0.18	0.02
30 - 60 cm	6.4	1.1	0.01	0.01	0.00	0.09	0.59	0.00	0.00	0.01
60 - 100 cm	6.9	1.7	0.00	0.01	0.00	0.09	1.1	0.00	0.07	0.00
Expl. variance (% R^2adj)	*50*	*16*	*46*	*2*	*19*	*46*	*20*	*0*	*2*	*0*
Peat soils:										
0 - 10 cm	3.6	0.39	0.17	0.09	0.27	0.41	0.64	1.1	1.9	0.11
10 - 30 cm	3.7	0.35	0.10	0.09	0.19	0.11	0.66	1.2	3.3	0.13
30 - 60 cm	3.8	0.47	0.06	0.06	0.22	0.02	0.99	3.7	4.3	0.08
60 - 100 cm	3.8	0.63	0.04	0.04	0.24	0.02	0.77	14	6.7	0.06
Expl. variance (% R^2adj)	*31*	*15*	*23*	*37*	*8*	*0*	*5*	*25*	*6*	*30*

6.3 Relations with the environmental characteristics

6.3.1 Deposition levels

Within the loess soils, the pH of the soil solution clearly (and significantly) decreased with increasing level of deposition of acidity (Table 94). A similar trend was found for the deposition of the separate compounds. Such a universal trend could not be distinguished for the clay and peat soils. For these soils only weak trends for some compounds were found.

The Ca concentrations in the loess soils decrease with increasing deposition levels, whereas the K and Al concentrations and the Al/Ca ratio increase with increasing deposition levels (Table 94). Like for the pH, this pattern only occurs for the loess soils. This indicates that the atmospheric input of acidity on loess soils is buffered by the dissolution of Al and by the release of base cations. These results indicate that at locations with low deposition levels, the deposition is still buffered by the dissolution and release of Ca, whereas at high deposition levels the release of K becomes more important.

Table 94 Median values of the pH and the nutrient concentrations and ratios in the soil solution as a function of the total deposition [1].

Deposition of acidity ($mol_c\ ha^{-1}\ a^{-1}$)	pH	Concentrations ($mol_c\ m^{-3}$)						Ratios ($mol\ mol^{-1}$)		
		Ca	K	Al	NH_4	NO_3	SO_4	NH_4/NO_3	NH_4/K	Al/Ca
Loess soils: [2]										
< 3000	-	-	-	-	-	-	-	-	-	-
3000 - 4000	7.0	2.8	0.16	0.03	0.05	1.6	0.93	0.03	0.31	0.01
4000 - 5000	4.1	0.92	0.16	0.21	0.05	0.98	0.82	0.07	0.26	0.14
5000 - 6000	4.1	0.78	0.17	0.25	0.05	0.78	0.77	0.07	0.32	0.30
6000 - 7000	3.8	0.72	0.24	0.81	0.07	1.4	1.1	0.06	0.37	0.66
7000 - 8000	-	-	-	-	-	-	-	-	-	-
> 8000	-	-	-	-	-	-	-	-	-	-
Expl. variance (% R^2_{adj})	*33*	*9*	*14*	*28*	*22*	*0*	*0*	*7*	*0*	*26*
by NH_x deposition	*27*	*14*	*4*	*27*	*25*	*0*	*0*	*4*	*4*	*29*
by NO_x deposition	*15*	*19*	*2*	*6*	*1*	*0*	*0*	*2*	*0*	*17*
by N_{tot} deposition	*30*	*20*	*5*	*26*	*21*	*0*	*0*	*5*	*2*	*32*
by SO_x deposition	*20*	*0*	*19*	*17*	*13*	*0*	*9*	*6*	*0*	*9*
Clay soils:										
< 3000	-	-	-	-	-	-	-	-	-	-
3000 - 4000	-	-	-	-	-	-	-	-	-	-
4000 - 5000	5.7	0.78	0.01	0.06	0.01	0.21	0.60	0.05	0.61	0.05
5000 - 6000	6.8	2.2	0.01	0.00	0.00	0.14	0.77	0.00	0.00	0.00
6000 - 7000	5.9	1.1	0.01	0.04	0.00	0.13	0.81	0.01	0.14	0.02
7000 - 8000	6.5	1.3	0.01	0.01	0.00	0.13	0.70	0.00	0.08	0.01
> 8000	5.5	0.32	0.01	0.17	0.01	0.04	0.49	0.32	0.64	0.24
Expl. variance (% R^2_{adj})	*0*	*2*	*0*	*0*	*1*	*0*	*0*	*3*	*3*	*0*
by NH_x deposition	*6*	*1*	*10*	*0*	*0*	*0*	*0*	*0*	*1*	*0*
by NO_x deposition	*5*	*3*	*0*	*0*	*4*	*0*	*0*	*8*	*3*	*0*
by N_{tot} deposition	*0*	*0*	*4*	*0*	*0*	*0*	*0*	*0*	*2*	*0*
by SO_x deposition	*13*	*19*	*0*	*3*	[illegible]					
Peat soils:										
< 3000	3.3	0.22	0.08	0.08	0.30	0.57	0.60	0.36	2.6	0.19
3000 - 4000	3.2	1.1	0.05	0.15	0.53	0.69	1.3	1.1	5.7	0.15
4000 - 5000	3.6	0.33	0.07	0.06	0.17	0.03	0.57	4.1	2.9	0.10
5000 - 6000	4.1	0.96	0.09	0.04	0.21	0.02	0.69	4.6	3.4	0.06
6000 - 7000	3.6	0.40	0.07	0.08	0.33	0.06	0.77	4.7	4.1	0.15
7000 - 8000	3.8	0.46	0.01	0.08	0.33	0.31	0.68	2.4	3.0	0.07
> 8000	-	-	-	-	-	-	-	-	-	-
Expl. variance (% R^2_{adj})	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
by NH_x deposition	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*0*
by NO_x deposition	*25*	*22*	*27*	*1*	*1*	*0*	*0*	*0*	*28*	*27*
by N_{tot} deposition	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
by SO_x deposition	*19*	*3*	*20*	*0*	*0*	*0*	*0*	*1*	*3*	*7*

1) Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

2) Data for loess soils based on layers 0-10 cm, 10-30 cm and 60-100 cm only.

The increase in the N deposition levels (NH_x and NO_x) is reflected in the increasing NH_4 concentrations for the loess soils (Table 94), but the N deposition is also correlated with various other variables. Such trends can hardly be distinguished for the clay and peat soils. Some of the variables in the peat soils are correlated with the NO_x deposition.

6.3.2 Tree species and stand characteristics

Tree species

Within the **loess soils**, the highest values for the pH occur below the 'other deciduous species' (with poplar as the most characteristic species) (Table 95). This cluster also shows the highest Ca, NO_3 and SO_4 concentrations, the lowest Al and NH_4 concentrations and the lowest values for the three ratios. For this tree species cluster the input of N and acidity is buffered relatively quick by the release of Ca. Differences in soil solution composition are relatively small between the other three tree species clusters on loess soils.

The variation in the soil solution variables in **clay soils** is only for the Ca concentration significantly correlated with the tree species. The Al concentration and the Al/Ca ratio are also correlated with the tree species, but these variables are both in a range that is not relevant. For the other variables the tree species is not very explanatory for the variation.

Table 95 Median values of the pH and the nutrient concentrations and ratios in the soil solution as a function of the tree species [1]*.*

Tree species	pH	Concentrations ($mol_c\ m^{-3}$)						Ratios ($mol\ mol^{-1}$)		
		Ca	K	Al	NH_4	NO_3	SO_4	NH_4/NO_3	NH_4/K	Al/Ca
Loess soils: [2]										
Oak	4.1	0.63	0.15	0.34	0.05	0.93	0.74	0.07	0.37	0.37
Beech	4.0	0.49	0.20	0.28	0.06	1.2	0.83	0.07	0.29	0.43
Other deciduous	4.6	2.0	0.20	0.11	0.04	1.5	1.1	0.04	0.30	0.03
Conifers	4.0	0.81	0.29	0.55	0.05	0.65	0.97	0.11	0.37	0.95
Expl. variance (% R^2_{adj})	*20*	*29*	*4*	*37*	*4*	*0*	*10*	*7*	*3*	*53*
Clay soils:										
Poplar (pure)	6.4	1.6	0.01	0.01	0.00	0.18	0.89	0.00	0.07	0.00
Poplar (mix)	6.4	1.4	0.01	0.01	0.00	0.14	0.71	0.00	0.13	0.01
Other deciduous	5.6	0.67	0.01	0.06	0.00	0.10	0.56	0.08	0.39	0.06
Expl. variance (% R^2_{adj})	*9*	*37*	*0*	*27*	*3*	*1*	*6*	*0*	*4*	*35*
Peat soils:										
Birch	3.7	0.33	0.08	0.08	0.40	0.03	0.79	5.5	4.9	0.14
Birch + oak	3.6	0.56	0.06	0.08	0.18	0.18	0.63	0.89	2.6	0.10
Birch + alder	4.6	0.54	0.15	0.03	0.18	0.02	0.72	1.4	0.97	0.05
Expl. variance (% R^2_{adj})	*30*	*0*	*14*	*25*	*27*	*4*	*0*	*8*	*33*	*26*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.
[2] Data for loess soils based on layers 0-10 cm, 10-30 cm and 60-100 cm only.

The largest differences in the soil solution variables in the **peat soils** were found for the pH, which is considerably higher for the stands with alder than for the other stands (Table 95). The lowest Al concentrations and lowest Al/Ca and NH_4/K ratios were found for the same cluster. The pure birch stands show the lowest Ca concentrations and the highest NH_4 concentrations and also the highest values for all three ratios.

Stand characteristics

Within the **loess soils**, the only significant correlation with the **canopy coverage** was found for the pH. However, the observed pattern with the highest value for the middle class canopy coverage is hard to explain. Furthermore, there are positive correlations between the canopy coverage and the Ca, SO_4 concentrations and to a less extent NO_3 concentrations and negative correlations with the Al concentrations and the Al/Ca ratio, although these correlations are not significant (Table 96). This pattern indicates that for the forests on loess soils a higher canopy coverage may cause higher deposition rates of SO_x, NO_x and NH_x, which is mainly buffered by the release of Ca by the soil. However, Ca deposition may be enhanced as well. Significant positive correlations with the **tree height** were found for the pH. Furthermore, positive but non-significant correlations are found for almost al elements, except NH_4, and consequently negative correlations with the NH_4/NO_3 and NH_4/K ratios (Table 97). This may indicate that an increase in tree height enhances the deposition of S and N compounds and of base cations. It may also indicate that the trees become higher on soils with a more favourable soil solution composition, which is also reflected in the pattern for the pH. Regarding NH_4, nitrification processes seem to counteract the larger N inputs.

Table 96 Median values of the pH and the nutrient concentrations and ratios in the soil solution as a function of the canopy coverage [1].

Canopy coverage (%)	pH	Concentrations ($mol_c\ m^{-3}$)						Ratios ($mol\ mol^{-1}$)		
		Ca	K	Al	NH_4	NO_3	SO_4	$\frac{NH_4}{NO_3}$	$\frac{NH_4}{K}$	$\frac{Al}{Ca}$
Loess soils: [2]										
< 50%	4.0	0.36	0.20	0.45	0.05	1.0	0.66	0.07	0.32	1.1
50 - 75%	4.1	0.60	0.18	0.34	0.05	0.78	0.79	0.08	0.28	0.38
> 75%	4.0	0.95	0.17	0.37	0.06	1.3	0.92	0.06	0.32	0.20
Expl. variance (% R^2_{adj})	*21*	*6*	*0*	*4*	*0*	*0*	*0*	*0*	*0*	*10*
Clay soils:										
< 50%	6.2	1.2	0.01	0.03	0.01	0.13	0.60	0.03	0.11	0.02
50 -75%	6.2	1.1	0.01	0.01	0.00	0.24	0.97	0.01	0.09	0.01
> 75%	6.2	1.2	0.01	0.02	0.00	0.12	0.65	0.01	0.13	0.01
Expl. variance (% R^2_{adj})	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*0*
Peat soils:										
< 50%	-	-	-	-	-	-	-	-	-	-
50 - 75%	3.6	0.41	0.09	0.07	0.28	0.03	0.88	4.7	3.7	0.11
> 75%	3.8	0.50	0.08	0.08	0.21	0.12	0.60	1.4	2.7	0.09
Expl. variance (% R^2_{adj})	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*1*	*1*	*0*

1) Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

2) Data for loess soils based on layers 0-10 cm, 10-30 cm and 60-100 cm only.

Within the **clay soils**, there are no significant correlations between the **canopy coverage** and the chemical composition of the soil solution (Table 96). However, this problem may also be caused by the uneven distribution of the stands over the canopy coverage classes. Clear (but non-significant) correlations with **tree height** were found for the SO_4 concentration (positively) and for the NH_4/K ratio (negatively) (Table 97). There are no other obviously linear trends. For N, the N transformation processes and the uptake by trees and ground vegetation most probably counteract the large N input. However, the class with a tree height between 5 and 10 m has considerably lower pH values and Ca concentrations and considerably higher Al concentrations and NH_4/NO_3 and Al/Ca ratios. This indicates either that these stands remained low because of the relatively unfavourable soil chemical conditions, or that these stand are really young, so that the soil solution composition is still influenced by the conditions of a recent clear-cut.

Table 97 Median values of the pH and the nutrient concentrations and nutrient ratios in the soil solution as a function of the tree height [1]*.*

Tree height (m)	pH	Concentrations ($mol_c\ m^{-3}$)						Ratios ($mol\ mol^{-1}$)		
		Ca	K	Al	NH_4	NO_3	SO_4	$\frac{NH_4}{NO_3}$	$\frac{NH_4}{K}$	$\frac{Al}{Ca}$
Loess soils: [2]										
0 - 5 m	-	-	-	-	-	-	-	-	-	-
5 - 10 m	-	-	-	-	-	-	-	-	-	-
10 - 15 m	4.0	0.54	0.11	0.17	0.06	0.82	0.48	0.12	0.42	0.31
15 - 20 m	4.1	0.67	0.19	0.25	0.06	0.93	0.81	0.08	0.34	0.27
> 20 m	4.1	0.98	0.19	0.33	0.05	1.3	0.96	0.06	0.26	0.37
Expl. variance (% R^2_{adj})	*22*	*5*	*0*	*3*	*0*	*0*	*3*	*0*	*0*	*0*
Clay soils:										
0 - 5 m	-	-	-	-	-	-	-	-	-	-
5 - 10 m	4.9	0.34	0.01	0.08	0.01	0.16	0.45	0.09	1.7	0.15
10 - 15 m	7.1	1.2	0.00	0.01	0.00	0.04	0.63	0.02	0.25	0.01
15 - 20 m	6.1	1.1	0.01	0.03	0.00	0.23	0.68	0.00	0.07	0.02
> 20 m	6.3	1.2	0.01	0.02	0.00	0.13	0.70	0.01	0.10	0.01
Expl. variance (% R^2_{adj})	*15*	*54*	*8*	*0*	*5*	*13*	*0*	*3*	*4*	*10*
Peat soils:										
0 - 5 m	-	-	-	-	-	-	-	-	-	-
5 - 10 m	3.6	0.28	0.05	0.06	0.33	0.02	0.51	4.6	5.8	0.13
10 - 15 m	3.8	0.72	0.09	0.08	0.19	0.18	0.71	1.7	2.1	0.07
15 - 20 m	-	-	-	-	-	-	-	-	-	-
> 20 m	-	-	-	-	-	-	-	-	-	-
Expl. variance (% R^2_{adj})	*0*	*25*	*17*	*0*	*2*	*20*	*2*	*15*	*22*	*8*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

[2] Data for loess soils based on layers 0-10 cm, 10-30 cm and 60-100 cm only.

Within the **peat soils**, there is a positive (non-significant) correlation of the **canopy coverage** with the pH and with the NO_3 and Ca concentrations, and a negative correlation with the NH_4 and SO_4 concentrations and with the ratios (Table 96). This indicates that for the peat soils a reduction of the canopy coverage is mainly correlated with worse chemical conditions. Positive correlation with the **tree height** classes are found for the Ca, K, Al, NO_3 and SO_4 concentrations, and a negative correlation for the NH_4 concentration and for all the three ratios, although these correlations are mostly not significant (Table 97). As with the loess soils, this pattern may indicate that the higher stand have a larger input of S and N compounds and of base cations. These stands seem to have a better nitrification as well. In general, it seems that low canopy coverage and low trees result from adverse chemical (and hydrological) conditions, rather than that these stand properties determine the soil solution composition.

6.3.3 Surrounding land use characteristics

The observed surrounding land use characteristics comprise the distance to the nearest forest edge, the type of land use beyond this edge and the direction of this edge with respect to the forest stand. The results with respect to the latter aspect is not covered separately an a table. The results for the soil solution with respect to the first two aspects are covered in Tables 98 and 99, respectively.

In general, the SO_4 and Ca concentrations decrease with increasing distance to the forest edge for all three parent materials and for the K and NO_3 concentrations in the loess soils (Table 98). An increase with increasing distance to the forest edge was found for the NH_4/K ratio in the loess soils and the Al concentration and the NH_4/NO_3 and Al/Ca ratios in the clay soils. These patterns give a weak indication for a higher S, N and base cation deposition closer to the forest edge. Especially for peat soils, no trends are observed for the N compounds (NH_4 and NO_3), indicating that differences in N transformation may be more important than differences in N deposition.

Table 98 Median values of the pH and the nutrient concentrations and ratios in the soil solution as a function of the distance to the nearest forest edge [1].

Distance to nearest forest edge (m)	pH	Concentrations ($mol_c\ m^{-3}$)						Ratios ($mol\ mol^{-1}$)		
		Ca	K	Al	NH_4	NO_3	SO_4	$\frac{NH_4}{NO_3}$	$\frac{NH_4}{K}$	$\frac{Al}{Ca}$
Loess soils: [2]										
0 - 20 m	4.0	0.98	0.27	0.47	0.04	0.93	1.5	0.05	0.14	0.38
20 - 40 m	4.3	1.9	0.24	0.13	0.05	1.2	1.2	0.04	0.21	0.07
40 - 60 m	4.2	1.0	0.15	0.13	0.05	1.1	0.74	0.05	0.37	0.10
60 - 80 m	4.1	1.1	0.16	0.37	0.06	1.4	0.89	0.06	0.35	0.23
80 - 100 m	4.0	0.61	0.16	0.35	0.05	1.2	0.77	0.07	0.47	0.64
> 100 m	4.1	0.42	0.12	0.28	0.06	0.65	0.54	0.09	0.44	0.50
Expl. variance (% R^2_{adj})	*18*	*14*	*22*	*16*	*0*	*0*	*19*	*0*	*31*	*19*
Clay soils:										
0 - 20 m	5.9	1.3	0.01	0.02	0.00	0.19	1.3	0.00	0.00	0.01
20 - 40 m	6.2	1.2	0.01	0.02	0.00	0.13	0.70	0.01	0.09	0.01
40 - 60 m	6.4	1.8	0.00	0.01	0.00	0.17	0.72	0.00	0.00	0.01
60 - 80 m	6.3	1.6	0.01	0.02	0.00	0.09	1.3	0.01	0.04	0.01
80 - 100 m	5.7	0.42	0.01	0.06	0.01	0.11	0.37	0.06	1.1	0.09
> 100 m	6.9	0.77	0.02	0.05	0.00	0.19	0.47	0.02	0.25	0.08
Expl. variance (% R^2_{adj})	*0*	*4*	*0*	*0*	*0*	*0*	*9*	*0*	*0*	*0*
Peat soils:										
0 - 20 m	3.8	0.47	0.07	0.06	0.28	0.01	0.54	9.2	4.1	0.10
20 - 40 m	3.6	0.93	0.09	0.07	0.15	0.39	0.99	0.56	1.7	0.07
40 - 60 m	3.4	0.33	0.10	0.12	0.53	0.80	1.1	1.1	5.2	0.18
60 - 80 m	3.8	0.35	0.07	0.09	0.08	0.33	0.58	0.69	1.3	0.05
80 - 100 m	3.3	0.22	0.08	0.08	0.30	0.57	0.60	0.36	2.6	0.19
> 100 m	3.9	0.33	0.05	0.05	0.24	0.01	0.62	17	5.3	0.10
Expl. variance (% R^2_{adj})	*0*	*0*	*10*	*0*	*0*	*27*	*5*	*31*	*13*	*0*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

[2] Data for loess soils based on layers 0-10 cm, 10-30 cm and 60-100 cm only.

Within the loess soils, the locations near maize fields had the lowest pH values and the highest K, Al, NO_3 and SO_4 concentrations (Table 99). The lowest Ca concentrations and the highest Al/Ca ratios occur near arable land. This indicates that these locations near maize fields have the highest inputs of N and S compounds and of base cations. The high rate of nitrification in these soils level all the differences in the N inputs, so that no significant difference occur in the NH_4 concentrations.

Within the clay soils, only five out of 30 locations are not bordering grass land, which makes a good comparison nearly impossible. Despite this uneven distribution, the surrounding land use type gives a very significant explanation for the variation in the NH_4 concentrations and the NH_4/NO_3 ratios (Tables 99 and 102). For the locations near grass lands, the NH_4 concentrations and the NH_4/NO_3 ratios are lower than for the location near other land use types. However, the difference is mainly a difference between 0 concentrations of NH_4 for the locations near grass land and non-0 but almost 0 for the locations near other land use types. Therefore, these difference do hardly have a serious meaning, despite the statistically significant correlation.

Table 99 Median values of the pH and the nutrient concentrations and ratios in the soil solution as a function of the land use type beyond the nearest forest edge [1].

Land use type beyond edge	pH	Concentrations ($mol_c\ m^{-3}$)						Ratios ($mol\ mol^{-1}$)		
		Ca	K	Al	NH_4	NO_3	SO_4	$\frac{NH_4}{NO_3}$	$\frac{NH_4}{K}$	$\frac{Al}{Ca}$
Loess soils: [2]										
Maize field	4.0	0.78	0.26	0.48	0.05	1.3	1.1	0.03	0.25	0.38
Arable land	4.1	0.54	0.14	0.44	0.04	0.62	0.85	0.08	0.26	0.54
Grass land	4.1	0.83	0.15	0.25	0.05	1.0	0.79	0.06	0.32	0.20
Other	4.2	0.81	0.20	0.39	0.06	0.89	0.95	0.08	0.34	0.43
Expl. variance (% R^2_{adj})	*0*	*0*	*10*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
Clay soils:										
Maize field	-	-	-	-	-	-	-	-	-	-
Arable land	6.3	0.92	0.00	0.01	0.01	0.10	0.55	0.08	0.39	0.01
Grass land	6.3	1.2	0.01	0.03	0.00	0.14	0.70	0.01	0.09	0.02
Other	6.4	1.4	0.01	0.01	0.02	0.08	0.88	0.10	2.6	0.00
Expl. variance (% R^2_{adj})	*0*	*0*	*0*	*1*	*6*	*7*	*0*	*14*	*12*	*0*
Peat soils:										
Maize field	3.5	0.33	0.06	0.08	0.25	0.09	0.77	2.7	4.6	0.15
Arable land	4.1	0.68	0.09	0.04	0.24	0.01	0.39	10	3.9	0.08
Grass land	3.7	0.37	0.07	0.07	0.25	0.07	0.77	2.2	3.8	0.11
Other	3.8	0.51	0.09	0.08	0.22	0.11	0.63	1.6	2.7	0.10
heath land	3.9	0.44	0.06	0.05	0.23	0.03	0.60	5.9	4.4	0.14
reed land / water	3.6	0.54	0.09	0.09	0.19	0.49	0.73	1.0	2.1	0.29
Expl. variance (% R^2_{adj})	*0*	*5*	*0*	*1*	*25*	*2*	*0*	*21*	*2*	*0*
incl. heath, reed/water	*36*	*2*	*0*	*19*	*23*	*21*	*5*	*39*	*5*	*8*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

[2] Data for loess soils based on layers 0-10 cm, 10-30 cm and 60-100 cm only.

6.3.4 Site characteristics

Soil types

Within the loess soils, the Fluvisols differ strongly from the three other clusters (Table 100). The Fluvisols have the highest values for the pH and for the Ca, K, NO_3 and SO_4 concentrations and the lowest values for the Al and NH_4 concentrations and for all the three ratios. The highest values for the Al and NH_4 concentrations and for the three ratios are found in the Cambisols, either in loamy or in sandy loess. The pattern for the differences in soil solution composition amongst the clusters resembles the pattern for the solid phase (nutrient content and exchangeable cations), although correlations have not been calculated. The pH values in the soil follow the same pattern as the pH(H_2O) and the pH(KCl). The levels of the soil solution pH are in between these two values for the mineral soil. The Ca and K concentration correlate well with the base saturation, whereas the Al/Ca ratio correlates well with the Al occupation. The NO_3 concentration correlate well with the (reversed) C/N ratio.

The largest differences between the soil types within the clay soils were found between the Calcaric Fluvisols and the two types of Eutric Fluvisols (Table 100). The calcareous soils had higher values for the pH and the Ca concentrations and lower values for the Al concentration and Al/Ca ratio. This differences are closely related to the availability of (calcium) carbonates in these soils. There were no remarkable differences in soil solution composition between the other two soil type clusters.

Table 100 Median values of the pH and the nutrient concentrations in the soil solution as a function of the soil type [1].

Soil type	pH	Concentrations ($mol_c\ m^{-3}$)						Ratios ($mol\ mol^{-1}$)		
		Ca	K	Al	NH_4	NO_3	SO_4	NH_4/NO_3	NH_4/K	Al/Ca
Loess soils: [2]										
Eutr.Cambisol, sandy l.	4.1	0.30	0.14	0.33	0.04	0.59	0.52	0.08	0.35	0.49
Eutr.Cambisol, loamy l.	4.0	0.74	0.17	0.40	0.06	1.2	0.77	0.07	0.37	0.31
Hapl.+Gl. Luvisol	4.0	1.1	0.19	0.33	0.04	1.1	1.1	0.05	0.27	0.18
Eutr.+Cal. Fluvisol	5.6	3.2	0.28	0.08	0.04	1.6	1.5	0.03	0.19	0.02
Expl. variance (% R^2_{adj})	*31*	*48*	*1*	*8*	*0*	*4*	*31*	*7*	*11*	*31*
Clay soils:										
Eutr. Fluvisol, med.-text.	6.0	0.99	0.01	0.05	0.01	0.12	0.66	0.08	0.22	0.03
Eutr. Fluvisol, fine-text.	6.2	1.2	0.01	0.03	0.00	0.14	0.75	0.00	0.04	0.02
Calcaric Fluvisol	7.2	2.1	0.00	0.01	0.00	0.12	0.42	0.00	0.33	0.00
Expl. variance (% R^2_{adj})	*25*	*10*	*8*	*24*	*17*	*1*	*4*	*26*	*20*	*20*
Peat soils:										
Fibr. Histosol high m.	3.5	0.32	0.04	0.08	0.24	0.10	0.63	3.2	5.7	0.16
Terr. Histosol, high m.	3.6	1.1	0.09	0.11	0.18	0.63	0.11	0.56	1.7	0.08
Fibr. Histosol, low m.	4.2	0.55	0.11	0.04	0.24	0.10	0.44	20	2.6	0.06
Expl. variance (% R^2_{adj})	*29*	*17*	*15*	*8*	*0*	*37*	*31*	*49*	*10*	*13*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

[2] Data for loess soils based on layers 0-10 cm, 10-30 cm and 60-100 cm only.

Within the peat soils, the largest differences in soil solution composition are found between the soils in the low moor area and the soils in the high moor area

(Table 100). The soils in the low moor area have the highest pH, the highest K concentrations and the highest NH_4/NO_3 ratios and lowest Al/Ca ratios. This is an indication that these soils are slightly buffered, e.g. by groundwater or nearby surface water or by (the combination of) hampered nitrification and enhanced denitrification. The Terric Histosols showed the highest values for the Ca and NO_3 concentrations and the lowest values for the NH_4 and SO_4 concentrations and the NH_4/NO_3 and NH_4/K ratios. This indicates that nitrification and other decomposing processes run relatively quick in these soils.

Drainage classes

Within the loess soils, the highest values for the pH and for the Ca, K and SO_4 concentrations occur at the moist locations (Table 101). The dry locations have the highest values for the Al, NH_4 and NO_3 concentrations and for the NH_4/K and Al/Ca ratios.

Within the clay soils, hardly any differences occur in the composition of the soil solution amongst the drainage classes, except for an increase in the SO_4 concentration going from wet to dry (Table 101).

Within the peat soils, only a few parameters show a consistent trend with the drainage class (Table 101). The highest values for the Ca, K and NO_3 concentrations are found in the wettest soils. The highest values for the three ratios are found in the driest soil. The NH_4 concentration is hardly affected by the drainage class.

Table 101 Median values of the pH and the nutrient concentrations and ratios in the soil solution as a function of the drainage class [1].

Drainage class	pH	Concentrations ($mol_c\ m^{-3}$)						Ratios ($mol\ mol^{-1}$)		
		Ca	K	Al	NH_4	NO_3	SO_4	$\frac{NH_4}{NO_3}$	$\frac{NH_4}{K}$	$\frac{Al}{Ca}$
Loess soils: [2]										
Moist	4.6	1.3	0.25	0.15	0.03	0.41	1.3	0.08	0.16	0.10
Dry	4.1	0.78	0.17	0.29	0.06	1.1	0.79	0.06	0.33	0.30
Expl. variance [3] (% R^2_{adj})	*2*	*2*	*7*	*0*	*8*	*2*	*11*	*0*	*20*	*4*
Clay soils:										
Wet	6.4	1.5	0.01	0.01	0.01	0.11	1.2	0.01	0.10	0.01
Moist	6.5	1.6	0.01	0.01	0.01	0.22	0.77	0.00	0.04	0.01
Dry	5.8	0.68	0.01	0.01	0.07	0.11	0.53	0.07	0.31	0.06
Expl. variance (% R^2_{adj})	*7*	*40*	*0*	*24*	*13*	*9*	*21*	*14*	*14*	*34*
if continuous classes (Dr_c)										
Peat soils:										
Wet	4.1	0.38	0.09	0.03	0.21	0.01	0.44	20	3.1	0.06
Moderately drained	3.4	0.36	0.07	0.09	0.26	0.26	0.79	1.5	3.6	0.16
Excessively drained	3.5	0.97	0.08	0.12	0.30	0.69	0.98	0.59	2.7	0.10
Expl. variance (% R^2_{adj})	*40*	*0*	*0*	*36*	*0*	*49*	*21*	*41*	*0*	*10*
if continuous classes (Dr_c)	*38*	*0*	*0*	*34*	*0*	*45*	*20*	*42*	*0*	*8*

[1] Note that the results for the presented classes may be affected by the uneven distribution of these classes over other environmental characteristics.

[2] Data for loess soils based on layers 0-10 cm, 10-30 cm and 60-100 cm only.

[3] No difference between nominal classes and continuous classes.

6.3.5 Statistical analysis

Table 102 gives an overview of the accounted variance by the all different environmental characteristics as a result the multiple regression. For the soil solution the simple statistical model comprises the factors 'tree species', 'soil type' and 'drainage class'.

For the loess soil, the variation in the pH, the Ca and NO_3 concentrations and the NH_4/NO_3 and Al/Ca ratios are explained best the entire simple statistical model (Table 102). For the K and NH_4 concentrations the best explanation is based on the drainage class and the tree species, thus excluding the soil type as predictor (compare with Table 100). The SO_4 concentration is explained best by the soil type and the tree species only, although the drainage class as a separate factor also explained 17% (Table 101). The NH_4/K ratio is the only variable for which the tree species was not selected as a relevant variable.

Extension of the statistical model with all other environmental factors results in the addition of the deposition levels for all observed parameters, except the Ca concentration and the NH_4/NO_3 and NH_4/K ratios (Table 102). The deposition variables are negatively correlated with the pH and positively correlated with the concentrations of K and Al. This indicates that atmospheric deposition on the loess soils has resulted in the a decreasing pH values and in the release of Al and base cations (possibly from the exchange complex, see Section 5.2.3). The deposition levels are also positively correlated with NH_4 and SO_4 concentrations and in the Cambisols in sandy loess also with the NO_3 concentrations. This indicates that also the deposition itself can be detected in the soil solution.

Besides the elements form the simple model and the deposition variables, also various other environmental characteristics appear in the selected 'best models', e.g. the adjacent land use type and the distance and direction of the forest edge. These stand characteristics may probably be correlated with subtle differences in deposition or with differences in transpiration or evaporation (which may induce concentration of the soil solution).

For the clay soils, all three elements of the simple statistical model have been selected for the Ca and Al concentrations and the Al/Ca ratio (Table 102). The soil type has been selected for all variables except NO_3. The tree species appeared to be relevant for the variation in all variables except the K, NO_3 and SO_4 concentrations.

Extension of the statistical model with all other available environmental characteristics shows that atmospheric deposition is not relevant for most soil solution variables in the clay soils (Table 102). Only the Ca concentration is affected in all distinguished soil types, whereas the pH and the Al/Ca ratio are only affected in part of the soil types. The Ca concentration is positively correlated with the atmospheric deposition, indicating that acidic inputs are buffered by the release of base cations (especially Ca). The selected relationships with the deposition levels for the pH (in the Calcareous soils) and Al/Ca ratio (in the light textured Fluvisols) were opposite as expected.

Table 102 Best explaining environmental characteristics for the pH and the nutrient concentrations and nutrient ratios in the soil solution, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	$\%R^2_{adj}$	Sign.[3]	Factors	$\%R^2_{adj}$	Sign.[3]
Loess soils: [4]						
pH	So + Dr + Tr	38	**	So + Tr + Dp_t + La	69	***
Ca	So + Dr + Tr	60	***	So + Dr + Tr + Ds	66	***
K	Dr + Tr	8	-	Dp_{so} + Ds + Tr	50	***
Al	Tr	37	***	Tr + Dp_t	57	***
NH_4	Dr + Tr	9	-	Dr + Dp_t + Di + Ds	44	***
NO_3	So + Dr + Tr	18	*	So + Dr + Dp_n.So	41	**
SO_4	So + Tr	31	**	So + Ds + Dp_{so}	52	***
NH_4/NO_3	So + Dr + Tr	17	*	So + Dr + Di	24	*
NH_4/K	So + Dr	20	*	Dr + Ds + Di	48	**
Al/Ca	So + Dr + Tr	60	***	So + Tr + Dp_t + La	82	***
Clay soils:						
pH	So + Tr	34	**	So + Dr + Dp_{so}.So	59	***
Ca	So + Dr + Tr	52	***	So + Dr + Di + Dp_{so}	63	***
K	So	8	-	So + Dp_{no}.So	36	**
Al	So + Dr + Tr	57	***	So + Dr + Ds	61	***
NH_4	So + Tr	24	*	So + Di	34	**
NO_3	Dr	9	-	Dr	9	-
SO_4	So + Dr	25	*	Dr + Di	37	**
NH_4/NO_3	So + Tr	30	*	So + Di	34	**
NH_4/K	So + Tr	25	*	So + Tr	25	*
Al/Ca	So + Dr + Tr	62	***	So + Dr + Tr + Ds + Dp_{so}.So	81	***
Peat soils:						
pH	So + Dr + Tr	67	***	Dr + Tr + Dp_{no} + Di + Dr_c.Dp_{no}	79	***
Ca	So	17	*	So	17	*
K	So + Dr + Tr	30	*	So + Dr + Tr + He + Ds_w + Di	76	***
Al	Dr + Tr	52	***	Dr + Tr	52	***
NH_4	So + Dr_c + Tr	28	*	So + La + Dr_c	66	***
NO_3	So + Dr	53	***	Dr + Ds_w + Dp_{no}	69	***
SO_4	So	31	**	So	31	**
NH_4/NO_3	So + Dr + Tr	57	***	So + La_2	72	***
NH_4/K	So + Tr	40	**	So + He + Dp_t	65	***
Al/Ca	So + Dr + Tr	43	**	So + Dr + Tr + Dp_{no}.So + Dr_c.Dp_{no}	68	***

1) Simple model: analysis only with 'Soil Type', 'Drainage Class' and 'Tree Species' (coding cf. Section 2.4).
2) Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).
3) Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)
4) Data for loess soils based on layers 0-10 cm, 10-30 cm and 60-100 cm only.

The distinguished soil types within the peat soils are the one and only best predictor for the variation in the Ca and SO_4 concentrations in the peat soils (Table 102). The analysis of the simple model resulted in the selection of all three predictors for the explanation of the variation in the pH, the concentrations of K and NH_4 and the ratios of NH_4/NO_3 and Al/Ca. The drainage class appears also not to be relevant for the Al concentration and the NH_4/K ratio. Moreover, the tree species seems not to be relevant for the variation in the NO_3 concentration.

Extension of the model with all other available predictors results in the selection of deposition variables for the pH, the NO_3 concentrations and the NH_4/K and Al/Ca ratios. The relations for the pH and the Al/Ca ratio, however, were opposite as expected. The pH increases with increasing deposition levels, and the Al/Ca ratios decrease. Only in the dryer soils, a decrease in pH is estimated with increasing deposition levels. This might indicate that only excessively drained peat soils are subject to acidification as a result from atmospheric deposition. The correlation between atmospheric deposition and the Al/Ca ratio is obscured by the interactions with the soil type and the drainage class. This may, however, indicate that both the soil type (admixture of mineral particles) and the proximity of groundwater may play a role in the buffering of atmospheric inputs of acidity. The NO_3 concentration is positively correlated with the deposition level, especially of NO_x. The NH_4/K ratio is also positively correlated with the deposition levels, thus indicating that the deposition also affects the relative availability of nutrients for the vegetation of forests on peat soils. The NO_3 and K concentrations are also positively correlated with the distance to the nearest open water or reed land.

6.4 Summary and conclusions

The following summarizing conclusions can be drawn from the preceding sections:

1. The **pH values** in the soil solution decrease from clay soils > loess soils > (sandy soils) > peat soils. This order reflects the similar order for the pH(H_2O) and the pH(KCl). The pH increases with depth for all three parent materials, which for the loess and peat soils is similar to the pH(H_2O) and pH(KCl).

2. For the **loess soils**, the soil solution composition indicates that most of these soils are considerably affected by the deposition of N (and S) compounds, as manifested in the high NO_3, SO_4 and Al concentrations and high Al/Ca, NH_4/Mg and $(NH_4+NO_3)/SO_4$ ratios. The low NH_4 concentrations indicate, however, that nitrification is not hampered. Within the loess soils, the fluvial soils are far less affected by the atmospheric deposition, due to the large available buffer capacity of exchangeable cations and (at some locations) of carbonates.

3. For the **clay soils**, the soil solution does not indicate that these soils are adversely affected by atmospheric deposition. The pH values and the Ca and Si concentrations indicate that these soils are well buffered by the initial stage of the cation exchange buffer and for some locations even still by the carbonate buffer. The inputs of NH_4 are quickly nitrified and successively taken up or, especially in the wet soils denitrified. Only the topsoil of medium textured soils under beech or oak, seem to be affected, as indicated by the Al and NH_4 concentrations and the NH_4/K ratio.

4. For the **peat soils**, the soil solution indicates that the input of acidity is mainly buffered by the release of (exchangeable) base cations and locally by base cations from surface or seepage water. Although most peat soils have very low pH values, the Al concentrations are low, which is mainly due to the little amount of easily weatherable Al containing minerals. Atmospheric input of acidity is mainly buffered by cation exchange and in the low moor area also by the availability of base cations from nearby mesotrophic surface water. The high NH_4 concentration indicate the nitrification might be hampered, whereas the low NO_3 concentrations indicate that denitrification plays an important role, except in the very topsoil and at the driest and most earthified locations. Denitrification might have a significant share in the buffering of acid deposition. Shallow water-tables and good groundwater quality (low N concentrations, moderate base cation concentrations) might be important factor in counteracting adverse effects of atmospheric deposition.

7 Discussion

Several aspects are subject for discussion with in the framework of this study. All these items can be ordered in two categories, namely (i) the setup if the inventory and the applied predictor variables and statistical methods (Section 7.1), and (ii) the limitation of the present inventory and the possible need to extend and use these data in the future (Section 7.2).

7.1 Setup of this inventory

7.1.1 Selection and representativity of the locations

The locations were selected by means of different selection methods. Only part of the locations were fully random selected, namely the locations on loess that were part of Dutch 1 km x 1 km forest condition monitoring network. All other plots were selected from other projects and on by expert judgement of maps and other information. This means that from a statistical point of view this is not a fully representative sample. On the other, it would have been practically impossible to select enough locations based on a fully random sample, e.g. by selecting (part of) the intersection of a gridnet with a certain fixed density. Such a strategy would be seriously hampered by the scattered nature of the occurrence of forests on the investigated soils, that would also fully fulfil the criteria for selection and for which the owner would give consent for taking soil samples.

The criteria used in the selection of 'suitable' sampling plots may also imply limitations on the representativity of the locations for making global interpretations of all similar soils in the Netherlands. One important limitations was that calcareous soils were explicitly excluded during the selection procedure. It was only more or less by accident that a few plots with a few percents of lime in the soil were included. For a proper analysis of the impact of atmospheric deposition on calcareous loess and clay soil, a separate analysis should have been made, based on a more representative set of sampling plots. The inclusion of a few calcareous plots in the present inventory over-estimate the significance of conclusions over calcareous soil and decrease the number of non-calcareous plots.

Except from the accidental inclusion of some calcareous soils, the criteria were rather strict, which resulted in relatively homogenous sets of locations. The homogeneity of the set of locations, however, may also limit the possibilities for the extrapolation of the results. This counts mostly for the clay and peat soils. The representativity of the selected plots with loess seems sufficient for the extrapolation to all loess soils under forest, except for the calcareous loess soils. The plots on clay soils are concentrated in Holocene fluvial clay soils and within these soils mostly in backswamp areas. Plots on Pleistocene (and older) deposits with a clayey texture were hardly selected and plots on marine clay soils were not selected at all. Justification for this choice is that the area of forest on older deposits is very small in comparison with the area of forests on Holocene clay soils. The forest on marine clay soils occur almost completely on calcareous clay soils and should therefore be dealt with in a separate inventory of the chemical composition of calcareous clay soils under forest.

The selection of plots on peat soils were almost completely limited to plots dominated by birch and to ecosystems which could be characterized as 'high moor' or 'high moor-like' (in the low moor area). A significant part of the forests on peat soils were excluded, namely the significant area of peat soils covered with alder (alder carr), which covers large parts of the forests in the low moor area, and forests on peat in narrow river valleys and in swamps. It was assumed that the inputs of atmospheric deposition in these ecosystems are buffered by seepage water or surface water in these ecosystems and that the nitrogen cycle is strongly affected by the nitrogen fixing capacity of the alder roots. Since this kind of ecosystems were not included, it is still not fully clear whether these buffer mechanisms can fully counter atmospheric inputs. The results for the cluster 'Birch + alder' can only give same vague indications. There is evidence from other investigations that at least the topsoil and the ground vegetation are affected by atmospheric N inputs. It should, however, also be considered that changes in the drainage status and in the quality of the groundwater can have large impacts. Increasing drainage can cause oxidation and acidification and the groundwater quality may have large influence on the extend of which deposition (or internal production) of acidity can be buffered.

7.1.2 Importance of the applied predictor variables

The results have been correlated with various stand and site characteristics. These characteristics can be separated in the characteristics which can estimated from maps or other data bases (soil type, drainage class and tree species), and other characterises.

The characteristics soil type, drainage class and tree species were expected to be most important for the determination of the differences in the soil chemical variables. This inventory proved that one or more of these variables could give a good explanation of the observed variation. For several variables, however, it was clear that a relatively homogeneous set of locations was selected. If this was the case, the basic characteristics were not selected by the applied statistical methods. The second reason why the variables are important is they are available for extrapolation to other locations. The clustering can, however, be arbitrary. If more locations would have been available, a more detailed clustering could have been included in the statistical analysis. The results of this analysis could then haven been used to make a more sensible clustering, which both would give a better explanation of the observed values and would offer more certain values for extrapolation. Furthermore, the impact of the drainage class could haven been quantified in more detail, by using any relationship between the drainage class and the depth of the groundwater, with respect to the ground surface or the depth of the sample.

The predictor variable 'soil type' included a combination of factors that could sometimes also be used as separate predictor variables. This is, for instance, the case for the clay soils, where two main types were distinguished, based on their clay content, and a third one based on a deviating carbonate content but with very variable clay contents. In an alternative approach it would have been possible to keep these carbonate rich in the main clusters, and include the carbonate content as an additional predictor variable. A similar adaptation would be possible for the peat soils for the difference between 'low moor' and 'high moor' vs. Fibric and Terric Histosols. Currently, the cluster 'Fibric Histosols in the low moor area' already one Terric Histosol.

The usability of all other predictor variables in further analysis and for extrapolation is limited. Most of these characteristics have to be assessed at each individual spot or have to be calculated or measured (especially deposition). Furthermore, it is not always clear what is the mechanism behind a selected relationship, especially for stand characteristics such as direction to the forest edge, the adjacent land use type and the tree height. Sometimes, the values for stand characteristics are more an effect of observed soil chemical characteristics, rather than a cause. This applies specifically for tree height and canopy closure, but may partially also apply for the tree species, since the tree species choice is at least partially determined by site characteristics, which implicitly include various soil chemical variables.

For the deposition levels, only the levels for the year 1991 were included. It was implicitly assumed that these values were representative for the deposition levels during the previous ten or even more years, since the present soil chemical status is the result of many years of deposition. The spatial variation is considered to be more important than the year-to-years variation in the deposition. Since the year-to-year variation is still considerable, whereas the correlation was made for one year values, it is not possible to apply the found relationships with deposition on different locations with deposition level for a different year.

7.2 Further analysis and extension of the data

7.2.1 Single response analysis vs. multiple response analysis

The statistical analysis has fully be carried out using the various response variables one by one. This gives appropriate results for the explanation of the observed variation of the individual variables and also offers good possibilities for the extrapolation of the results for the individual variables. For reasons of the selection of the most important predictors for the variation in the present chemical status of the soils, it would be interesting to combine the results for different relevant variables into one analysis. A selection of relevant variable should therefore be made of available variables, including a weighing factor between these variables. Multi-variate analyses can be carried out for various aspects (and possibly various layers): acidification status, eutrophication status, drainage of nutrients, heavy metal (pollution) status. The application of multi-variate analysis in soil chemical research, however, is still under development.

7.2.2 Assessment of chemical relationships and constants

The statistical analysis of the present inventory was limited to the relationships between the observed soil chemical variable and various stand and site characteristics. This is a valid approach. For some relationships, it might have been more useful to use different predictor soil chemical variables as additional or alternative predictor variables to explain the variation in the considered response variable. Many relationships can be tested, e.g. between soil phase and soil solution variables.

This approach might be valuable for two reasons: (i) to assess the correlation between different variables, which can then be used to estimate values for a missing variable if other variables are known (i.e. a correlative approach) or (ii) to investigate certain chemical processes, equilibria etc. in order to assess certain specific chemical characteristics or contents of the soil (i.e. the process-based approach).

7.2.3 Combination of different parent materials

In this study, we have analysed the three parent materials completely indepently. In a further analysis it might be useful to combine the results from loess, clay and peat soils. This broadens the variation in many relevant variables. Since much more variation is included, it is less likely that all kinds of unexpected relationships will be selected in the best explaining model. The selection of this kind of predictors could possibly mainly be blamed to the homogeneity of the set of locations within each set. This kind of analysis can also be extended with the results from the 150 forest stands on poor sandy soils and data from other inventories that have a similar setup and treat the same chemical variables. For a complete coverage of all forest soils of the Netherlands, this inventory may be completed with an inventory of the soil types that were not in one of earlier inventories (Section 7.3.3).

Combination of the analysis of data for all these set requires that the layers for which data were collected are comparable. Most important limitation, currently, are the layers in the 150 stands on poor sandy soils (De Vries & Leeters, 1999). That survey included the chemical composition of the humus layer (all important solid phase variables), the chemical composition of the mineral soil for the layer 0-30 cm (all important solid phase variables) and the chemical composition of the soil solution for the layers 0-30 cm and 60-100 cm (all important variables). This means that for the humus layer all results are more or less comparable. Only for the clay soils no data are available, except the thickness, due to the almost absence of such a layer on most of these soils. For the mineral soil only the data for the top 30 cm can be compared. The mineral soil data for the layers 0-10 cm and 10-30 cm for the loess, clay and peat soils have to be combined into one value per location for the layer 0-30 cm. This can be achieved by using the average value which should also account for the differences in thickness and bulk density. Soil solution data can be compared for the layers 0-30 and 60-100 cm, for which, again, thickness-weighed averages have to be calculated over the layers 0-10 cm and 10-30 cm.

The resulting data sets can be used for several purposes. These are comparable with the aims for the present inventory. An important advantage is, that the effect of possible predictor variables that occur in different sets of locations can be estimated for precisely, e.g. the relationship with drainage status or tree species. In the present studies, the effect of these predictors can easily be separated from the effect of other predictors. Nation-wide conclusions could be drawn of certain environment processes as a function of soil type, drainage class, tree species etc., e.g. for acidification, eutrophication and leaching of nutrients. Furthermore, such a combined approach gives more possibilities for a nation-wide extrapolation of results, e.g. for the initialization of scenario studies. It might also become possible that small groups of plots from different surveys can be combined into larger groups, e.g. the Fluvisols within the loess soils with the Light-textured Fluvisols within the clay soils and all calcareous soils into one group.

When the results from different surveys are combined into one analysis, it should, however, be considered that the effect of some environmental predictors is different in the distinguished groups of a different predictor. The is probably the case in the effect of atmospheric deposition. Such differences have to be countered by the inclusion of interaction terms. This was already necessary in the present study, considering different effects of atmospheric deposition on some variables, depending on the soil type. In-depth analysis of such interactions could lead to clusters with and clusters without a certain effect.

7.2.4 Completion of parent materials

The present study covers a large group of soils under forest ecosystem which are almost complementary to the 150 stand on poor sandy soils (De Vries & Leeters, 1999). In this study, however, it was mentioned that still various soil types are missing. Some of these are partly included because there are transition zones between the investigated soil types and the excluded ones. Soil types (parent materials) that need to be further investigated, in order to complete the nation-wide character of this set of inventories are:

- calcareous clay and loam soils (incl. floodplain soils),
- low moor peat soils,
- maritime clay soils (mostly calcareous) and,
- calcareous sandy soils (incl. dune soils).

Finally, some attention has to be paid to the occurrence of soils that consist of two different parent materials within the top 60 to 100 cm. In the present study and also in the inventory of the 150 stands on poor sandy soils, the plots were only included if the top 100 cm consisted of the same parent material. There is, however, a considerable area of forest occurring on soils that have a transition from one parent material to a different one within 100 cm from the surface. Sometimes, the chemical and physical characteristics of these parent materials are completely different, although they may affect each other. It is still far from clear whether it is possible to apply the values from the separate materials (based on uniform profiles) for these soils.

8 Conclusions

The conclusions of this investigation are linked to the three main aims of this researched mentioned in Section 1.1:

1. give an overview of the chemical soil composition (buffer capacity and N-enrichment) and soil solution chemistry (acidification status) of non-calcareous loess, clay and peat soils in the Netherlands;
2. give insight in the relationship between the chemical composition of humus layer, mineral soil and soil solution with deposition level, stand characteristics and site characteristics;
3. provide data for further use in model simulations to predict long term impacts of the deposition of nitrogen and acidity on these forest soils.

First an overview is given of the main conclusions with respect to the chemical composition of the investigated soils, focusing on the acidification and eutrophication status and the relationship of relevant variables with various environmental characteristics (Aim 1 and Aim 2). Firstly, this is done by collecting all relevant conclusions for the considered variables, followed by the generilized answers on the main questions. Finally some remarks are made about the usefulness of the collected data for further research (Aim 3).

Results of this investigation

The general conclusions of this investigation, related to the individual variables included in this study, are as follows:

- The thickness of the humus layer and the pools of organic matter and nutrients in the humus layer decreased from loess soils > peat soils > clay soils (if any). They are all smaller than for the sandy soils and the decrease (also within the parent materials) generally follows the decrease in vulnerability for acidification and eutrophication.
- The N contents (of the organic matter) for the humus layer of loess and peat soils is slightly higher than for sandy soils. The N contents (of the organic matter) for the mineral soil generally decreased from clay soil > loess soils > (sandy soils) > peat soils. Within the parent materials, the N content is positively correlated with the deposition level and with the expected vulnerability for eutrophication.
- The contents and pools of P (in the organic matter) and P_{ox} and the P_{ox}/P_{tot} ratio in the mineral soil decrease from clay soils > loess soils > (sandy soils) > peat soils and decrease with depth. The P contents (in the organic matter) in the humus layer are much lower, but follow the same pattern.
- The NH_4 and NO_3 concentrations and ratios indicate that all three parent materials have high deposition rates of N compound. In most loess and clay soils these inputs are quickly nitrified and in the wet soils also denitrified. Only in the most vulnerable loess soils and in the topsoils of medium-textured clay soils under oak or beech adverse N conditions occur in the soils solution. High NH_4 concentrations in most peat soils indicate that nitrification might be hampered in these soils. Especially under wet conditions denitrification seems to be very important in these soils.

- The contents of Ca, Mg and K in the humus layer decreased from loess soils > (sandy soils) > peat soils.
- The contents of Pb, Cu and Ni in the humus layer decreased from (sandy soils) > loess soils > peat soils, whereas the Zn and Cd increased in this order. The Pb, Zn and Cd frequently exceeded the so-called Target Values, especially for the loess soils.
- The Al_{ox} and Fe_{ox} contents decreased from clay soils > loess soils > peat soils > (sandy soils). The pools for peat soils are, however, much smaller than for sandy soil. Within the three groups, contents and pools generally increase with the expected decrease in vulnerability to acidification.
- The CEC (of the organic matter) in the humus layer decreased from loess soils > sandy soils > peat soil. In the mineral soil, the CEC of the peat soils was almost completely determined by the organic matter content (and the pH), whereas the CEC for the loess and clay soils was determined by the clay and organic matter contents. The CEC of the clay is considerably less effective for loess soils than for 'regular' clay soils
- The base saturation in the humus layer decreased from loess soils > (sandy soils) > peat soils, whereas for the mineral soils it decreased from clay soils > peat soils > loess soils > (sandy soils). This indicates that the base saturation for the peat soils is relatively low in the humus layer and relatively high in the 'mineral' soil. The base saturation increased with depth for the clay and peat soils. Within the acid cations, the peat soils had high H occupation and low Al occupation.
- The pH(H_2O) and pH(KCl) and the pH in the soil solution generally decreased from clay soils > loess soils > (sandy soils) > peat soils and increased with depth for all soils. For the humus layer the pH values for loess and peat soils compare very well on a 0.5 unit higher level than for the sandy soils.
- The composition of the soil solution of the clay soils and the fluvial loess soils indicates that these soils are not adversely affected by atmospheric deposition. The pH values and the Ca and Si concentrations indicate that these soils are well buffered by the initial stage of the cation exchange buffer and for some locations even by the carbonate buffer. Only the topsoil of the most vulnerable subtypes seems affected.
- The composition of the soils solution of the non-fluvial loess soils (Luvisols and Cambisols) indicates that the are seriously affected and that the are in the lower range of the cation exchange buffer.
- The composition of the soils solution of the peat soils indicate acidification from atmospheric deposition is well buffered by the release of base cations and sometimes by base cations from surface or seepage water. The Al concentrations are low, despite low to very low pH values, due to the limited availability of easily weatherable Al containing minerals. Large-scale denitrification in wet peat soils may also play an important role in the buffering of the input of acidifying compounds. Shallow water-tables and good groundwater quality (low N concentrations, moderate base cation concentrations) might be important factor in counteracting adverse effects of atmospheric deposition.

The general conclusions about the chemical composition of the loess, clay and peat soils, with respect to the acidification and eutrophication status and the most important determining environmental characteristics, are:

- There is no evidence that the thickness and pool of the humus layer on the loess, clay and peat soils is affected by atmospheric deposition. Soil type and tree species are the dominant determinants.
- Most non-calcareous loess soils are moderately acidic, and should be considered as highly vulnerable for further acidification. The fluvial loess soils and the medium-textured clay soils are vulnerable for acidification at the longer term. The fine-textured clay soils are not acidified and also not vulnerable for acidification. Most peat soils are naturally acidic, and anthropogenic acidification can hardly be separated from the natural acidity and natural acidification.
- Most loess and peat soils are considerably affected by the continuous deposition of nitrogen. Especially the nutrient poor soil types show excess N values and the risk of induced deficiencies of other elements. The fluvial loess soil are less vulnerable, due to the higher availability of other elements, like the clay soils. The peat soils in the low moor area are less vulnerable, mostly due to the water-logged conditions in most of these soils. The eutrophication in the peat soils in the high moor area might be worsened by mineralisation related to excess drainage. The effects are most distinct in the topsoil and the humus layer.
- Slightly elevated heavy metal contents are found in the humus layer, especially for the elements with atmospheric inputs (Pb, Cd and Zn). Slightly elevated heavy contents in the topsoil (0-10 cm) are mainly found in the clay soils. Serious pollution with heavy metals was not found in any of the sampled locations.

Usefulness of data for further use

The following conclusions can be drawn with respect to the usefulness of the collected data for further studies:

- The data provide consistent and representative sets of values for the chemical composition of loess, clay and peat soils under forests in the Netherlands.
- The data for the soil solution are representative for the years in which the soils were sampled, but are less representative for other years. These data may be useful as initial values in scenario studies or for validation purposes.
- The data for the mineral soil and for the humus layer can be considered as useful values for a longer period of time (several years) and can thus be used as fixed values in certain scenario studies.
- There are certain limitations in the applicability of the data, due to the strict selection criteria: no reliable estimates can be provided for calcareous soils (loess and clay), maritime clay soils and real low moor peat soils.
- For most investigated variables, the set of 'universally available' stand and site characteristics (i.e. soil type, drainage class and tree species) can provide reasonable estimates. There are, however, also many correlations with environmental characteristics that are not easily available for scenario and upscaling studies.
- The estimated coefficients for the relevant stand and site characteristics may improve considerably by combining the data for the three observed soil types here and also the sandy soils. Even the soil types that are now still missing could then be included.

References

Bolt, A.J.J., H.J. Mücher, J. Sevink & J.M. Verstraten, 1980. A study on loess-derived colluvia in Southern Limbourg (The Netherlands). *Netherlands Journal of Agricultural Science* 28:110-126.

Breeuwsma, A. & O.F. Schoumans, 1986. Fosfaatophoping en –uitspoeling in de bodem van mestoverschotgebieden. Wageningen, Stiboka. Rapport 1866.

Chabra, R., J. Pleysier & A. Cremers, 1975. *The measurement of the cation exchange capacity and exchangeable cations in soil: a new method.* Proceedings International Clay Conference. Applied Publishing Ltd., Wilmette (Ill., USA). p. 439-449.

Clerkx, A.P.P.M, K.W. Van Dort & P.W.F.M. Hommel, 1994. *Broekbossen van Nederland.* Wageningen, IBN-DLO. IBN-rapport 96. 369 pp.

Coleman, N.T., S.B. Weed & R.J. McCracken, 1959. Cation exchange capacity and exchangeable cations in Piedmont Soils of North Carolina. *Soil Sci. Soc. J.* 23:146-149.

De Bakker, H., 1979. *Major soils and soil regions in the Netherlands.* The Hague, Junk. 203 pp.

De Bakker, H. & J. Schelling, 1989. *Systeem van bodemclassificatie voor Nederland, de hogere niveaus.* Second revised edition, edited by D.J. Brus and C. Van Wallenburg. Wageningen, Pudoc. 209 pp. + map + annex.

De Kroon, H., 1986. De vegetatie van Zuidlimburgse hellingbossen in relatie tot het hakhoutbeheer - een rijke wilde flora met onzekere toekomst. *Natuurhistorisch Maandblad* 75(10)167-192.

De Vries, F. & J. Denneboom, 1992. *De bodemkaart van Nederland digitaal.* Wageningen, DLO-Staring Centrum. Technisch Document 1.

De Vries, F. & C. Van Wallenburg, 1990. Met de nieuwe grondwatertrappenindeling met zicht op het grondwater. *Landinrichting* 30:31-36.

De Vries, W., 1991. *Methodologies for the assessment and mapping of critical loads and the impact of abatement strategies on forest soils.* DLO-Winand Staring Centre, Wageningen, the Netherlands, Report 46.

De Vries, W., 1993. *De chemische samenstelling van bodem en bodemvocht van duingronden in de provincie Zuid-Holland.* Wageningen (The Netherlands), DLO The Winand Staring Centre for Integrated Land, Soil and Water Research. Rapport 280. 31 pp.

De Vries, W., 1994. *Soil response to acid deposition at different regional scales. Field and laboratory data, critical loads and model predictions.* Ph.D Thesis, Wageningen, The Netherlands.

De Vries, W., 1996. *Critical loads for acidity and nitrogen for Dutch forests on a 1 km x 1 km grid.* DLO-Winand Staring Centre, Wageningen. Report 113.

De Vries, W. & J. Kros, 1989. *Lange termijn effecten van verschillende depositie-scenario's op representatieve bosbodems in Nederland.* Wageningen (The Netherlands), DLO The Winand Staring Centre for Integrated Land, Soil and Water Research. Rapport 30. 89 pp.

De Vries, W., A. Breeuwsma & F. De Vries, 1989. *Kwetsbaarheid van de Nederlandse bodem voor verzuring. Een voorlopige indicatie in het kader van de Richtlijn Ammoniak en Veehouderij.* Wageningen (The Netherlands), DLO The Winand Staring Centre for Integrated Land, Soil and Water Research. Rapport 29. 74 pp.

De Vries, W., A. Hol, S. Tjalma & J.C.H. Voogd, 1990. *Literatuurstudie naar voorraden en verblijftijden van elementen in bosecosystemen.* DLO-Staring centrum. Rapport 94. Wageningen.

De Vries, W. & E.E.J.M. Leeters, 1999. *Effects of acid deposition on 150 forest stands in the Netherlands. 1. Chemical composition of the humus layer, mineral soil and soil solution.* Wageningen (The Netherlands), DLO The Winand Staring Centre for Integrated Land, Soil and Water Research. Report 69.1.

Erisman, J.W., 1991. *Acid deposition in the Netherlands.* Rijksinstituut voor Volksgezondheid en Milieuhygiene, Report 723001002. 72 pp.

Erisman, J.W., 1993. Acid deposition onto nature areas in the Netherlands; Part I. Methods and results. *Water Air and Soil Pollution* 71:51-80.

FAO, 1974/1988. *FAO - Unesco soil map of the world 1 : 5 000 000.* Vol. 1 Legend. 59 pp. + 1 map. Vol. 5 Europe. 199 pp. + 3 maps.

Heij, G.J. & T. Schneider (Eds), 1991. *Acidification research in the Netherlands. Final report of the Dutch Priority Programme on Acidification.* Studies in Environmental Science 46. Amsterdam etc., Elsevier Publishers. 771 pp.

Hendriks, C.M.A., W. De Vries & J. Van den Burg, 1994. *Effects of acid deposition on 150 forest stands in the Netherlands. 2. Relationships between forest vitality characteristics and the chemical composition of foliage, humus layer, mineral soil and soil solution.* Wageningen (The Netherlands), DLO The Winand Staring Centre for Integrated Land, Soil and Water Research. Report 69.2. 52 pp.

Henriksen & Seip, 1980.Strong and weak acids in surface waters of Southern Norway and Southwestern Scotland. *Water Res.* 14:809-813, Hesse, P.R., 1971. *A textbook of soil chemical analysis*. New York : Chemical Publishing Co., 1971. - 520 p.

Jansen, P.C. & W. De Vries, 1994. *Effects of acid deposition on 150 forest stands in the Netherlands. 3. Input output budgets for sulphur, nitrogen, base cations and aluminium*. Wageningen (The Netherlands), DLO The Winand Staring Centre for Integrated Land, Soil and Water Research. Report 69.3. 60 pp.

Kleyn, C.E., G. Zuidema & W. De Vries, 1989. *De indirecte effecten van atmosferische depositie op de vitaliteit van Nederlandse bossen. 2. Depositie, bodemeigenschappen en bodemvochtsamenstelling van acht Douglas opstanden*. Wageningen (The Netherlands), Soil Survey Institute. Rapport 2050. 96 pp.

Klinka, K., R.N. Green, R.L. Trowbridge & L.E. Lowe, 1981. *Taxonomic classification of humus forms in ecosystems of British Columbia*. Province of British Columbia Ministry of Forests.

Kurmies, B., 1949. Humusbestimmung nach dem Bichromatverfahren ohne Kaliumjodid. *Zeitschrift für Pflanzenernährung Düngung und Bodenkunde* 44:121-125.

Kuyl, O.S., 1975. Löss. *Grondboor en Hamer* 29:2-12.

Leeters, E.E.J.M., H. Hartholt, W. De Vries & L.J.M. Boumans, 1994. *Effects of acid deposition on 150 forest stands in the Netherlands. 4. Assessment of the chemical composition of foliage, soil solution and groundwater on a national scale*. Wageningen (The Netherlands), DLO The Winand Staring Centre for Integrated Land, Soil and Water Research. Report 69.4. 156 pp.

Mekkink, P., 1989. *De bodemgesteldheid van "Object Savelsbos"*. Wageningen (The Netherlands), DLO The Winand Staring Centre for Integrated Land, Soil and Water Research. Rapport 13. 56 pp + 1 map.

Mekkink, P. & H. Kleijer, 1986. *De bodemgesteldheid, de vegetatie,de bodemgeschiktheid voor bosbouw en de te verwachten bosgemeenschappen in de boswachterij "Vaals"*. Wageningen (The Netherlands), Soil Survey Institute. Rapport 1810. 149 pp. + 9 maps.

Milieubalans, 1995-1998. *Milieubalans... : het Nederlandse milieu verklaard*. Bilthoven, Rijksinstituut voor Volksgezondheid en Milieuhygiene.

Mücher, H.J., 1973. Enkele aspecten van de löss en zijn noordelijke begrenzing, in het bijzonder in Belgisch en Nederlands Limburg en in het daaraan grenzende gebied in Duitsland. *K.N.A.G. Geogr. Tijdschr.* 7:259-276.

Natuurbalans, 1998. *Natuurbalans*. Bilthoven/Wageningen, Rijksinstituut voor Volksgezondheid en Milieuhygiene, DLO-Instituut voor Bos- en Natuuronderzoek, Landbouw-Economisch Instituut, DLO-Staring Centrum.

NBP, 1990. *Natuurbeleidsplan*. Ministerie van Landbouw, Natuurbeheer en Visserij. 's-Gravenhage.

NMP, 1989. *Nationaal milieubeleidsplan (NMP): kiezen of verliezen*. 's-Gravenhage: SDU, Min. VROM, Min. EZ, Min. L&V. Tweede Kamer der Staten-Generaal, Vergaderjaar 1988-1989, 21137, nrs. 1-2. 258 pp.

NMP-Plus, 1990. *Nationaal milieubeleidsplan-plus (NMP-Plus)*. 's-Gravenhage : SDU, Min. VROM, Min. EZ, Min. LNV. Tweede Kamer der Staten-Generaal, Vergaderjaar 1989-1990, 21137, nrs. 20-22. 111 pp.

Odé, B., 1990. Hakhoutbeheer, bodem en vegetatie. *Natuurhistorisch Maandblad* 79(7-8):208-212.

Oliver, B., E.M. Thurman & R.L. Malcolm, 1983. The contribution of humic substances to the acidity of colored natural waters. *Geochimica at Cosmochimica Acta* 47:2031-2035.

Pleysier, J.L. & A.S.R. Juo, 1980. A single-extraction method using Silver-thiourea for measuring exchangeable cations and effective CEC in soils with variable charge. *Soil Science* 129:205-211.

Projectgroep bosecosystemen, 1998. *Bossen op basenrijke gronden.* Wageningen, Instituut voor Bos- en Natuuronderzoek (IBN-DLO) en Staring Centrum, Instituut voor Onderzoek van het Landelijk gebied (SC-DLO). Concept November 1998.

Schwertmann, U., 1964. Differenzierung der Eisenoxide des Bodens durch Extraktion met Ammoniumoxalat-lösung. *Zeitschrift für Pflanzenernährung, Düngung und Bodenkunde* 105:194-202.

Soil Map of the Netherlands, scale 1 : 50 000, 1961-1994. Wageningen, Soil Survey Institute / DLO The Winand Staring Centre for Integrated Land, Soil and Water Research. Series of sheets with separate explanatory booklets.

Steur, G.G.L. & W. Heijink, 1991. *De Bodemkaart van Nederland, schaal 1 : 50 000. Algemene begrippen en indelingen.* 4e uitgave. Wageningen, DLO-Staring Centrum.

Stortelder, A.H.F., P.W.F.M. Hommel & R.W. De Waal, 1998. *Broekbossen.* Utrecht: KNNV Uitgeverij, Natuurhistorische bibliotheek 66. Bosecosystemen van Nederland 1. 216 pp.

Sverdrup, H. & P. Warfvinge, 1993. *The effect of soil acidification on the growth of trees, grass and herbs as expressed by the (Ca+Mg+K)/Al ratio.* Reports in Ecology and Environmental Engineering 1993:2, Lund University, Department of Chemical Engineering II, 108 pp.

Sverdrup, H. & W. De Vries, 1994. Calculating critical loads for acidity with a mass balance model. *Water Air Soil Pollut.* 72: 143-162.

Troedsson, T. & C.O. Tamm, 1969. *Small-scale variation in forest soil properties and its implications for sampling procedures.* Royal College for Forestry, Stockholm. Studia Forestalia Suecica, Nr 74. 30 pp.

USDA, 1975. *Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys.* Washington, USA Department of Agriculture, Soil Conservation Service, Soil Survey staff. USDA Handboork no 436. 754 pp.

Van de Westeringh, W., 1980. *Soils and their geology in the Geul valley.* In: W. Van de Westeringh et al.: Soil conditions, soil carbonates and former vegetation in the Geul valley from Gulpen to Meersen (South Limburg, The Netherlands). Wageningen, Veenman. Mededelingen van de Landbouwhogeschool, nr 80-8. Publicaties afdeling bodemkunde en geologie, nr 723. p. 1-25.

Van de Westeringh, W., 1981. Radebrikgronden in löss onder oud bos in Zuid-Limburg. *Natuurhistorisch Maandblad* 70:165-170.

Van Delft, S.P.J., 1996. *Bodemgesteldheid, enkele beheersaspekten en vegetatie in 208 opstanden van Robusta-populier.* Wageningen, DLO The Winand Staring Centre for Integrated Land, Soil and Water Research. Rapport 202. 217 pp.

Van den Broek, J.M.M. & H.W. Van der Marel, 1962. Calcium-magnesium and potassium-magnesium relations in loess soils of Limburg. *Boor en Spade* **12**: 103-110.

Van der Salm, C. & W. De Vries, 1998. Acidification of non-calcareous loess and clay soils in the Netherlands. Submitted to *Water Air Soil Poll.*

Van der Salm, C., L. Köhlenberg & W. De Vries, 1998. Weathering rates in loess and clay soils. *Geoderma* 85: 41-62.

Van den Akker, A.M. & J.N.B. Poelman, 1976. *Bodemkaart van Nederland schaal 1 : 50 000. Toelichting bij de kaartbladen 45 Oost 's-Hertogenbosch en 46 West - Oost Vierlingsbeek.* Wageningen, Soil Survey Institute. 209 pp.

Van den Berg, M.W., 1989. *Geomorfologische kaart van Nederland 1:50.000. Toelichting op kaartblad 59 Genk, 60 Sittart, 61 Maastricht, 62 Heerlen.* Wageningen, DLO Staring Centrum. Haarlem, Rijksgeologische Dienst.

Van den Broek, J.J.M. & H.G.M. Breteler, 1970. *Bodemkaart van Nederland schaal 1 : 50 000. Toelichting bij de kaartbladen 59 Peer en 60 West en 60 Oost Sittard.* Wageningen, Soil Survey Institute. 138 pp.

Van den Broek, J.M.M. & H.W. Van der Maarel, 1964. *De alluviale gronden van de Maas, de Roer en de Geul.* Bodemkundige Studies VII. 83 pp.

Van der Zee, S.E.A.T.M., W.H. Van Riemsdijk & F.A.M. De Haan, 1990a. *Het protocol fosfaatverzadigde gronden. Deel I: Toelichting.* Vakgroep Bodemkunde en Plantevoeding, Landbouwuniversiteit Wageningen.

Van der Zee, S.E.A.T.M., W.H. Van Riemsdijk & F.A.M. De Haan, 1990b. *Het protocol fosfaatverzadigde gronden. Deel II: Technische uitwerking.* Vakgroep Bodemkunde en Plantevoeding, Landbouwuniversiteit Wageningen.

Vink, A.P.A., 1949. *Bijdrage tot de kennis van loess en dekzanden: in het bijzonder van de Zuidoostelijke Veluwe.* Wageningen, Landbouwhogeschool. Dissertatie LH-147. 147 pp. + 6 sep. ann.

SBB/IKC-NBLF, 1983-1994. *De vitaliteit van het Nederlandse bos: verslag van de landelijke inventarisatie.* Utrecht, Wageningen: Staatsbosbeheer, IKC-NBLF.

Vleeshouwer, J.J. & J.H. Damoiseaux, 1990. *Bodemkaart van Nederland 1 : 50 000. Toelichting bij kaartblad 61-62 West en Oost Maastricht-Heerlen.* Wageningen, DLO The Winand Staring Centre for Integrated Land, Soil and Water Research. 177 pp.

Annex A Geogenesis and pedogenesis of loess, clay and peat soils

This annex gives some supplementary information on the geography, geogenesis and pedogenesis of the soil types concerned in this report. This information is not essential in the broad overview given in chapter 1, but helps understanding the occurring features and the variations on the general features.

A.1 Loess soils

Geogenesis

The original loess cover of the South Eastern part of the Netherlands is an eolian sediment from the Pleistocene, which covered almost completely the southern half of the province of Limburg. Within this loess belt the layer of loess deposits cover much of the underlying geological formations, which had been dissected before in several stages by branches of the river Meuse. The (actual) thickness of the loess deposit varies from less than 1 meter to almost 10 meters in the western part of Southern Limburg. Only on exposed positions, such as very steep slopes and high hill tops, the loess was not able to settle or was eroded easily shortly after sedimentation. On these sites the underlying material remained at the surface (Vleeshouwer & Damoiseaux, 1990; Van den Berg, 1989; Mücher, 1973).

Three distinct layers of loess have been distinguished in the original loess sediment, which reflect three different stages of sedimentation. However, they do not differ significantly in granular and mineral composition. The deposits are horizontally very homogeneous, which in flat areas is reflected in large soil units on the soil map. The presence of only a thin layer of loess and the occurrence of significant erosion make difference in this pattern. The soils in this original loess cover are called *in situ* loess soils (Kuyl, 1975; Vleeshouwer & Damoiseaux, 1990). The silt content of the loess decreases from south to north within the loess area. In general, the percentage < 50 μm is more than 85% (loamy loess) in the central and southern part of the loess belt, and 50-85% (sandy loess) in the northern part of it and in the scattered loess areas. The sandy loess forms the natural transition to the cover sand, also an eolian sediment, which covers vast areas in the south and east of the Netherlands.

The original loess cover still exists on the plateaus and on the higher river terraces. Other soils with a high content of loess have been formed as a result of slope processes, erosion and re-sedimentation. These loess-related soils are called secondary loess soils if the secondary deposit contains enough loam and is deep enough to be classified as a loess soil (Van den Broek & Van den Maarel, 1964; Bolt et al., 1980; Van de Westeringh, 1980; Vleeshouwer & Damoiseaux, 1990). Three types of loess-related soil types can be distinguished:

1. soils on steep slopes, which are highly influenced by slope processes, and which reflect both the different outcropping geological formations and the original loess cover;

2. colluvium on the lower slopes and in the narrow valleys, formed by the accumulation of various materials originating from positions higher on the slope; and
3. alluvium in the valleys and the river plains, formed by the fluvial sedimentation of loess-rich material, and colluvial loess-related soils which are not connected to the steep slope complexes.

The loess-related soils on the steep slopes and the colluvial soils on the lower parts of these slopes form the basis of many of the typical hill-side forests of Southern Limburg. The pattern of soil units on these slopes is very complex, because of the presence of original and eroded loess soils and different older outcropping geological formations, such as Maas terrace deposits, marine deposits, limestone and its weathering products (limestone-derived clay and flint), and glauconite clay. Slope processes, such as erosion and solifluction, did not only displace the different materials, but also mixed them. Besides, there are differences in pedogenesis in the different parent materials, and these materials have been subject to soil forming processes during different times. This complexity causes that the great number of different soil units on the slopes can only be mapped separately on very detailed maps. On the Soil Map of the Netherlands, scale 1 : 50 000 (1990) many of these soils had been mapped in complexes of several soil units. The following complexes have been distinguished, in relation to the underlying or outcropping geological formations (Vleeshouwer & Damoiseaux, 1990):
1. the glauconite slope complex,
2. the loess, terrace and limestone slope complex,
3. the limestone slope complex,
4. the loess and terrace slope complex, and
5. the flint stone slope complex.

The complex of loess, terrace and limestone slope soils can be regarded as the 'most complete' representative of the soils of the typical Southern Limburg hill-side forests, most common in the south-central part of Southern Limburg plateau (the 'Plateau of Margraten'). Going downhill the following sequence of forest soils can be found: the (partly eroded) original loess cover on the plateau edges, a zone with gravelly river terrace deposits, a zone with weathering products of limestone (limestone-derived clay or flint stone), a zone with the original limestone (only on steep slopes) and the colluvium near the valley bottom, consisting of the material of the different higher zones. The thickness of the gravelly terrace deposits decreases going eastward. This deposit is missing completely in the eastern and south-eastern part of Southern Limburg. Further north (e.g. the 'Plateau of Schimmert') the limestone and it weathering products do not outcrop (Vleeshouwer & Damoiseaux, 1990, De Kroon, 1986; Odé, 1990).

Alluvial loess soils have been formed by the sedimentation of loess-rich materials of the rivers in Southern Limburg: Geul and Meuse and some smaller streams. On the Soil Map of the Netherlands, scale 1 : 50 000 these soils are classified as soil with a fluvial origin, although they frequently have a content of loess-like material high enough for classifying them as loess soils. Especially along the river Meuse there is a gradual transition of fluvial loess-related soils to the strictly fluvial clay soil, on which will be reported elsewhere (Van den Broek & Van der Marel, 1964;

Vleeshouwer & Damoiseaux, 1990). Colluvial loess soils, which are not connected to the steep slope complexes, are less important in the framework of this project, because they carry only little forest.

Pedogenesis

The pedogenesis in loess soils and loess-derived soils comprises the following processes: decalcification, browning, biological homogenisation and clay eluviation and illuviation. In both *in situ* and secondary loess soils stagnating soil water or seepage water can cause features of oxidation and reduction.

The *in situ* loess soils have subject to these processes for a long time, resulting the typical soil profile of an old loess-loam soil. The original loess cover was in general rich in carbonates. After the decalcification of this parent material clay eluviation and illuviation became the most important soil forming processes. As a result of these processes all the old undisturbed non-eroded loess soil have an eluvial E-horizon and an illuvial texture B-horizon, the argillic B-horizon (Dutch: *briklaag*). Soils with such a profile are classified as '*brikgronden*', brick soils (De Bakker & Schelling, 1989) or Luvisols (FAO, 1988) if the thickness of the argillic B-horizon is at least 15 cm and if the fraction < 2 µm is at least 10%. Generally, in sandy loess parent material this profile is less pronounced. Erosion has caused the partial or even the complete removal of this typical soil profile, especially on the plateau edges and on the steeper slopes. On these sites the top of the soil profile is formed by a lower part of original soil profile: the eluvial E-horizon, the argillic B-horizon, the decalcified parent material or even the carbonate-rich parent material.

In the Dutch soil classification system (De Bakker & Schelling, 1989), the extent by which the original profile has been eroded is one of the keys of the classification of 'brick' soils, in combination with the absence or presence of hydromorphic properties. Complete profiles without hydromorphic properties are classified as 'Rade' brick soils. They mostly occur on plateaus and other very gently sloping areas. Profiles that have been eroded to the argillic B are called 'berg' (hill) brick soils. They mostly occur on plateau edges and in other steep sloping areas. Non-eroded profiles with hydromorphic properties up to the Ae horizon are called 'Kuil' (hole) brick soils, while profiles with hydromorphic properties up to the argillic B horizon are called 'Daal' (valley) brick soils. These two types mostly occur in flat areas in which a poor drainage status or impermeability of the soil causes stagnation of soil water. Sometimes hydromorphic properties are caused by seepage water.

Soils in more recent (secondary) loess deposits and on sites of which the original profile has eroded completely, do not have this typical soil profile or only a weakly developed one. Such profiles are no longer classified as brick soils, but as '*vague*' soils. In secondary loess soils soil forming processes are also influenced by the non-loess materials that has been mixed with the loess. On the longer term the typical loess profile will also develop in these soils, because clay eluviation and illuviation are still going on, provided that the parent material is low in carbonates.

A.2 Clay soils

Geography and geogenesis

As shortly indicated in Section 1.2.2 the spatial distribution of calcareous and non-calcareous clay soils is different for fluvial and marine clay soils. For the marine clay soils this distribution depends especially on the age of the soil and its position above or below sea level. For the (Holocene) fluvial clay soils this distribution depends on the position with regard to the river. Older fluvial clay soils occur near the (fossil) beddings of the rivers of the age the sediment was formed. The spatial distribution of the different types of marine clay soils and Holocene fluvial clay soils will be discussed here.

The marine clay soils have been deposited in several stages during the Holocene. The sea level rise during the Holocene caused each stage to have a maximum surface elevation above or below the current sea level. Four types of marine clay soils are distinguished according to the age of the upper part of the parent material, the origin, the period of enclosure and the elevation (De Bakker, 1979):

- drained lakes; shallow man-made lakes in the Provinces of South- and North-Holland, reclaimed between 1500 and 1950 A.D.; the upper part of the parent material (4-6 m below sea level) originates from 3000-1500 B.C. and is therefore also called 'old marine clay';
- coastal polders; coastal marshes outside dikes, reclaimed between 1200 A.D and present; the upper part of the parent material (0.5 m b.s.l. - 1.5 m a.s.l.) originates from 1200 A.D. - present;
- old land; natural forelands, bordering peat and Pleistocene, reclaimed before 1200 A.D.; the upper part of the parent material (1 m b.s.l. - 0.5 m a.s.l.) originates from 1500 B.C. - 1100 A.D.;
- Zuiderzee polders; shallow, wide marine lake, reclaimed between 1930 and present; upper part of the parent material (4-6 m b.s.l.).

Mostly the parent material was originally rich in carbonates. Only if the sediment contained a significant amount of organic matter, it can be initially non-calcareous. These soils mainly occur within the groups of 'drained lakes' and 'old land'. However the majority of area marine clay soils is formed by 'coastal polders' and 'Zuiderzee polders' (the two most recent types), which means that most marine clay soils are still calcareous. The non-calcareous marine clay soils occur in areas that have very little forest.

The Holocene fluvial floodplain has three major elements: forelands, natural levees and backswamp areas (De Bakker, 1979). The forelands lie outside the artificial levees or river walls, and are subject to flooding. The natural levees are the ridges that accompany actual and fossil river courses. They are 1 m higher than the surrounding backswamp area. The soils on the levees are characterized by a medium textured, well structured upper part of the solum overlying a coarse-textured subsoil. The soils are mostly calcareous, except for some levees along the river Meuse, which have less carbonates in their sediment, and for remnants of very old levees, which have been decalcified completely. The soils in the backswamp areas are fine-textured and non-calcareous. Especially in the western part of the area, peat can occur at shallow depth. Until recently these soils were badly drained, because groundwater levels were high and drainage conditions poor.

Conclusion of this discussion is, that the most extensive area of non-calcareous clay soils on which forests occur is formed by the backswamp areas of the river plains. The Holocene floodplain of the several branches of the rivers Rhine and Meuse is by far the largest area of fluvial clay in the Netherlands.

Pedogenesis
The most important soil forming processes in clay soils are ripening, decalcification, oxidation/reduction, browning and bioturbation.

Many of the soils in the marine and fluvial clay area are young or have been drained recently. Therefore, an unripened or partly ripened subsoil may occur, even below forest. The grade of ripening of the subsoil is an important key in the classification of clay soil in the Dutch soil classification system (De Bakker and Schelling, 1989), since most of them are distinguished as 'Nesvaag' soils. Most unripened or partly ripened subsoils are still ripening due to recent drainage and by the greater evapotranspiration of the forest, compared to grassland. On the long term the share of soils with unripened subsoil may well decrease.

Most marine clay soils and the soils of the natural levees in the river plains are deposited calcareously, especially those of the River Rhine and its branches. Decalcification is an important soil forming factor in these soils. The soils in the backswamps have been due to syn-sedimentary decalcification, related to the organic matter content of the very fine-textured material and the hydrological conditions. Also the soils in some of the deeper polders in the Marine clay area, of the sediment is overlying peat or has been mixed up with peat, are originally non-calcareous. However, non-calcareous and decalcified marine clay soils do hardly carry any forest.

Many clay soils show gleyic properties due to oxidation and reduction processes which are related to varying groundwater levels and a poor internal drainage. However, after drainage fossil gleyic features may remain in place for a long time. The presence of gleyic properties is an important key in the Dutch soil classification system (De Bakker & Schelling, 1989) for classifying ripened clay soils. Clay soils with gleyic properties are classified as 'Poldervaag' soil, while most clay soils lacking gleyic properties can be classified as 'Ooivaag' soils.

Browning and bioturbation are important soil forming processes in clay soils that are well drained during a long time. Weathering and accumulation of some organic matter makes the topsoil become browner than the parent material. In the Dutch system they are still classified as 'vague' soils, but according to the FAO system they must be classified as Cambisols, in contrast with the 'Poldervaag' soils which have remained (Gleyic) Fluvisols.

In the fluvial clay area most soils on the natural levees are calcareous and have a brownish topsoil. According to the Dutch system they are classified as 'Ooivaag' soils. In the FAO system these soils are classified as Calcaric Cambisols. Most soils in the backswamps are non-calcareous and have gleyic properties, which classifies them as 'Poldervaag' soils or Gleyic Fluvisols, respectively. Most of the ripened young marine clay soils are calcareous, lack the brownish topsoil and have gleyic properties, which classifies them as 'Poldervaag' soil or Calcaric Fluvisol, respectively.

A.3 Peat soils

Geogenesis

The peat of the high moor area has been formed in areas above sea level with a poor drainage and nutrient status. The peat formation started as fen peat in local depressions in the landscape, but later on peat covered large areas, including the former fens, forming large raised bogs. Generally, the peat soils existing before the start of human impact of the high moor area can be considered to be raised bogs with very oligotrophic conditions. Human impact on these soils started with drainage and some low-impact agricultural practices. However, when man started to reclaim these 'waste lands' for agricultural purposes and removed the peat for fuel, much of the original raised bogs disappeared. Now only small patches of high moor remain, within large cut-over areas. On most of these patches the present peat is only a part of the original peat layer, but on some patches the original layer of peat is still there. Part of the remaining peat soils is formed by the original fens and can hardly be considered as raised bogs. Besides a great part of these peat soils have been drained excessively, and can not be considered as 'living' (growing) raised bog. Only recently groundwater levels have been raised in order to regain or to stimulate the development of raised bog.

The peat of the low moor peat area has been formed in the wet area between the coastal ridges and the higher Pleistocene grounds. The peat formation started with eutrophic *Phragmites* (reed) peat, gradually shading off into sedge peat and *Sphagnum* moss peat. The growth of the peat kept pace with the sea level rise during many centuries. The low moor peat was intersected by the lower branches of the rivers Rhine, Meuse and Scheldt, and by tidal creeks. Floodings from these rivers and creeks caused the formation of mesotrophic and eutrophic wood peat close to these streams. Only further from the streams oligotrophic peat could form raised bogs. These raised bogs, which formed the bigger part of low moor area, had an elevation above sea level and above the surrounding water. During transgression periods large parts of the peat were removed, and replaced either by open water or marine clay deposits. The practice of digging peat increased again the amount of open water in the area. Many of these lakes have been reclaimed later-on. The remaining peat area has been drained for agricultural purposes. The drainage caused the peat to shrink and all these soils are below sea level now, which was the motive behind the name *low moor* peat soils. Actually most of the present growing peat soils in the low moor peat area can be considered as fen peat soils, because of the impact of eutrophic surface water. However most the present 'old' peat has been formed as raised bog at the time, and therefore must be consider as drowned high moor peat. Even now, living raised bogs are present or can be present in this area, if there is only little impact of surrounding open water or of seepage water.

Pedogenesis
Peat soils are organic soils in which the difference between geogenesis and pedogenesis is not very clear. In living peat soils geogenesis and pedogenesis are almost the same. However many of the peat soils are not living (growing) any more. In that case the existing peat layer can be considered as parent material. In this parent material several soil forming processes can take place. The most important actual soil forming processes are the oxidation and moulding (earthifying) of the existing peat, the accumulation of litter from the trees and the new-formation of peat. The most important soil forming factors are the existing site characteristics, the existing forest cover and the influence of man.

The oxidation of peat is an important process in drained peat soils. The increased availability of oxygen causes an increase of the decomposition rate, which causes increases nutrient availability and the acidification of the soil. The increased availability of nutrients causes an increase in tree growth. The deeper drainage allows the trees to find even more nutrients in deeper soil layer, which can be more eutrophic types of peat or even mineral subsoil layers. On the long term oxidation leads to the formation of an earthified topsoil. This process is enhanced by the addition of mineral material to the topsoil. This addition can be natural (eolian or fluvial sedimentation) or anthropogenic (additions to improve the accessibility or the tillability of the land). The difference between oxidized, earthified soils and 'original' peat soils is a major diagnostic property for both the Dutch (De Bakker & Schelling, 1979) as the FAO (1988) classification of peat soils.

On most peat soils the forest cover is fairly young and so is the accumulation of forest litter. On both the very wet and the extremely drained soils decomposition of forest litter can be inhibited, respectively due to extremely wet conditions and acid conditions. On the long term this litter may become more or less continuous with the underlying layers, forming a peat profile with a top layer that can be consider as wood peat, over more oligotrophic peat layers.

On very wet, relatively oligotrophic sites growth of peat by *Sphagnum* moss is still possible, even within forests. Forest with lots of *Sphagnum* mosses are an intermediate vegetation type between forests and living raised bogs. Some of these cases might gradually develop towards a living raised bog. On the long term tree seedlings will not be viable on this new-growth of peat, and the forest will gradually disappear.

Annex B Detailed list of the selected locations

This annex gives a detailed overview of the selected locations on loess, clay and peat soils. The lacking numbers for clay and peat soils are the locations that have been excluded. The list below contains the following information:

- the name of the location, mostly the name of forest the location is situated in, sometimes the name of a nearby place, river etc.
- the province the location is situated in
- the number of the sheet of the Topographic Map of the Netherlands the location can be found on
- the X- and Y-coordinates of the location in the standard coordinates system for the Netherlands
- the code of the observed soil type and water-table class according to the System of Soil Classification for the Netherlands, with the addition of a code for low (L) and high (H) moor for the locations on peat soils
- the main dominant tree species and
- the owner of the forest the location is situated in.

Table B.1 Detailed list of locations

Nr	Location name	Province	Map	X coor	Y coor	Soil type	Water-table cl.	Species	Owner
The locations on loess soils:									
L01	Onzalige Bosschen	Gelderland	33 D	199.850	450.850	Ln5	VIId	oak	*Natuurmonumenten*
L02	Hagenau	Gelderland	33 G	200.100	450.800	Ln5	VIId	oak	*Natuurmonumenten*
L03	Middachter Heide	Gelderland	33 G	201.650	450.350	Ld5	VIIId	oak	*Middachten* Castle
L04	Posbank	Gelderland	40 B	199.200	449.100	Ld5	VIId	oak	*Natuurmonumenten*
L05	Middachter Bosschen	Gelderland	40 E	202.100	449.850	Ld5	VIId	Jap.larch	*Middachten* Castle
L06	Kiekberg	Gelderland	46 B	192.100	417.940	Ld6g	VIIId	beech	*Natuurmonumenten*
L07	Ons Erf	Gelderland	46 B	192.450	424.900	Ld6g	VIIId	beech	*Ons Erf* Educ. centre
L08	Bunderbos	Limburg	68 D	180.980	327.010	Ld6g	VIIId	oak	State Forest Service
L09	Urmond	Limburg	68 D	182.000	333.000	BLh6	VIIId	maple	DSM
L10	Limbrichterbos - west	Limburg	68 D	186.025	337.040	Ln6g	VIIId	red oak	*Natuurmonumenten*
L11	Heringsbosch	Limburg	68 G	199.000	332.000	BLn6	Vao	Sc. pine	Reg. East S.Limburg
L12	Imstenraderbosch	Limburg	69 E	197.000	319.000	Hn21t	VIId	beech	City of Heerlen
L13	Douveweien	Limburg	69 E	197.000	320.000	Ldd6	VIIId	maple	City of Heerlen
L14	Holsetterbosch	Limburg	69 E	196.100	308.900	Ln6s	VIIId	oak	State Forest Service
L15	Kaldeborn	Limburg	69 E	198.000	321.000	Lnd6	Vao	alder	State Forest Service
L16	Geleenbeek - east	Limburg	69 E	194.000	323.000	Rn15C	Vao	poplar	not known
L17	Geleenbeek - west	Limburg	68 D	189.000	327.950	Rn15C	Vbd	poplar	not known
L18	Jeker valley	Limburg	69 B	175.000	314.900	Rd10A	VIId	poplar	*Limburgs Landschap*
L19	Geren valley	Limburg	69 B	188.250	316.070	BLh6	VIIId	maple	State Forest Service
L20	Bergse Heide	Limburg	69 B	183.360	319.460	gLdh6	VIIId	oak	State Forest Service
L21	Platte Bosschen	Limburg	69 E	196.700	313.800	BLn6	Va	poplar	State Forest Service
L22	Vijlenerbosch	Limburg	69 E	194.000	309.150	Ln6t	VIIId	oak	State Forest Service
L23	Kerperbosch	Limburg	69 E	195.850	309.050	Ln6t	VId	N. spruce	State Forest Service
L24	Malensbosch	Limburg	69 E	196.400	308.150	Ln6	VIIId	beech	State Forest Service
L25	Wolfhaag	Limburg	69 E	198.100	307.450	mLd6t	VIIId	bl. cherry	State Forest Service
L26	Onderste Bosch	Limburg	69 E	190.550	308.400	BLh6	VIIId	beech	State Forest Service
L27	Schweibergerbosch	Limburg	69 E	191.350	311.700	Ln6t	VIIId	birch	State Forest Service
L28	Groote Bosch	Limburg	69 B	188.500	309.900	gLh6t	VIIId	oak	State Forest Service
L29	De Molt	Limburg	69 E	190.050	310.000	Lh6s	VIIId	oak	State Forest Service
L30	Gulp valley (grass land)	Limburg	69 B	188.100	309.580	Ldd6	VIIId	none	State Forest Service

Nr	Location name	Province	Map	X coor	Y coor	Soil type	Water-table cl.	Species	Owner
L31	Riesenberg	Limburg	69 B	180.550	314.250	BLh6	VIIId	beech	State Forest Service
L32	Eijsderbosch	Limburg	69 B	180.600	310.950	BLb6	VIIId	birch	State Forest Service
L33	Savelsbos - north	Limburg	69 B	179.750	311.250	BLd6	VIIId	oak	State Forest Service
L34	Savelsbos - south	Limburg	69 B	180.400	312.450	Lh6	VIIId	red oak	State Forest Service
L35	Trichterberg	Limburg	69 B	180.650	313.525	lKRn2	VIIId	sw. chestn.	State Forest Service
L36	Heksenberg	Limburg	69 D	183.600	333.750	Ln5g	VIIo	red oak	DSM
L37	Vosbroek	Limburg	68 G	198.900	331.550	BLn6	Vao	birch	Reg. East S.Limburg
L38	Steinerbosch	Limburg	68 D	182.875	331.340	BLd6	VIIId	oak	City of Stein
L39	Meinweg	Limburg	58 G	206.500	354.700	Ld6g	VIIId	oak	Limb. Water Comp.
L40	Limbrichterbos - east	Limburg	68 D	187.000	337.350	BLn6	VIIId	oak	*Natuurmonumenten*

The locations on clay soils:

Nr	Location name	Province	Map	X coor	Y coor	Soil type	Water-table cl.	Species	Owner
K01	Markiezenbos	Utrecht	31 H	139.100	453.600	Rn44C	VII	ash	City of Utrecht
K02	Hoge Bos	Utrecht	32 C	140.100	454.200	Rn44C	VII	elm	City of Utrecht
K05	Overlangbroek	Utrecht	39 B	153.950	444.250	Rn44C	VIo	oak	State Forest Service
K06	Niënhof	Utrecht	32 C	142.350	454.100	Rn47C	Vbo	poplar	*Utrechts Landschap*
K07	Wulperhorst	Utrecht	32 C	143.800	452.900	Rn95C	VIo	poplar	*Utrechts Landschap*
K09	Hemmen	Gelderland	39 F	176.200	438.300	Rn44C	Vbo	oak	*Van Lynden* Found.
K10	Neerijnen	Gelderland	39 C	147.300	427.200	Rn94C	VIo	oak	*Gelders Landschap*
K12	Het Broek / Deil	Gelderland	39 C	143.200	429.100	Rn44C	IIIa	poplar	State Forest Service
K13	Heukelum	S. Holland	38 H	134.650	431.350	Rn45C	IIIb	poplar	not known
K18	De Nieuwe Wiel	Gelderland	39 D	158.400	426.500	Rn44C	IIIb	poplar	Mr. H. Jachtenberg
K19	Berenskampen	Gelderland	45 A	141.200	422.700	Rn44C	Vbo	poplar	State Forest Service
K23	Landgoed Bingerden	Gelderland	40 E	204.300	444.550	Rn44C	VIo	oak	*Bingerden* Estate
K24	Pierik (Angerlo)	Gelderland	40 E	208.050	443.950	KRn1	VIo	oak	not known
K25	Kasteel Keppel	Gelderland	40 F	212.800	445.200	Rn15C*F*	VIo	beech	*Pallandt v. Keppel* F.
K26	Rha	Gelderland	33 G	206.900	451.400	Rd90C	VIIo	ash	State Forest Service
K28	Vuilbemden	Limburg	58 D	198.650	358.500	*f*Rn95C	IIIa	poplar	Amev Live insur.
K30	Het Hoosden	Limburg	58 D	197.400	351.250	Rn95C	IIa	poplar	*Het Hoosden* Estate
K33	Overlangbroek - west	Utrecht	39 B	153.050	444.050	Rn47C	VIo	ash	State Forest Service
K36	Lingebos	Gelderland	38 H	131.300	428.750	Rn47C	Vb	poplar	State Forest Service
K45	Het Broek / Deil - west	Gelderland	39 C	142.950	429.000	Rn44C	IIIb	oak	State Forest Service
K46	Kolland	Utrecht	39 C	158.400	445.050	Rn95C	VI	poplar	*Kolland* Estate
K49	De Regulieren	Gelderland	39 A	146.600	438.200	Rn44C	IIIa	poplar	*Gelders Landschap*
K50	Lage Paarden	Gelderland	39 C	145.650	429.100	Rn44C	Va	poplar	Amev Live insur.
K51	Lieskampen	Gelderland	44 F	139.550	422.900	Rn44C	Va	gr. poplar	State Forest Service
K52	Personnenbos	Gelderland	40 C	180.900	428.200	Rn44C	VI	ash	State Forest Service
K55	Vlodrop	Limburg	58 G	203.550	350.250	Rn15C*F*	VI	poplar	not known
K57	Rampert	Gelderland	45 A	140.950	421.300	Rn44C	IIIb	poplar	State Forest Service
K58	Het Broek / Ewijk	Gelderland	39 H	176.450	429.500	Rn44C	Vbo	poplar	State Forest Service
K59	Het Broek / Altforst	Gelderland	39 G	167.300	430.200	Rn44C	Va	poplar	*De Sonneville*
K60	Neder- en Overasseltsche Broek	Gelderland	46 A	181.700	420.750	Rn44C	Vbo	poplar	State Forest Service

The locations on peat soils:

Nr	Location name	Province	Map	X coor	Y coor	Soil type	Water-table cl.	Species	Owner
V01	Naardermeer - Martelaarsgracht	N. Holland	25 H	136.100	478.900	L Vo	I	birch	*Natuurmonumenten*
V02	Naardermeer - Driehoek	N. Holland	25 H	135.300	479.650	L Vo	I	birch	*Natuurmonumenten*
V03	Naardermeer - Diemontsbos	N. Holland	25 H	135.750	480.000	L Vo	I	birch	*Natuurmonumenten*
V04	Botshol - Bruggesloot	Utrecht	31 E	123.500	474.200	L Vo	I	birch	*Natuurmonumenten*
V05	Botshol - Groote Wije	Utrecht	31 E	123.950	473.900	L aVc	I	birch	*Natuurmonumenten*
V06	Nieuwkoopse Plassen - w.	S. Holland	31 D	113.950	460.850	L Vc	IIa	birch	*Natuurmonumenten*
V07	Nieuwkoopse Plassen - e.	S. Holland	31 D	115.250	462.100	L Vc	I	birch	*Natuurmonumenten*
V08	Deurnsche Peel	N. Brabant	52 C	188.000	380.000	H aVs	VII	birch	State Forest Service
V11	Deurnsche Peel	N. Brabant	52 C	189.000	381.000	H aVs	IIIa	birch	State Forest Service
V12	Deurnsche Peel	N. Brabant	52 C	189.000	383.000	H aVs	VI	birch	State Forest Service
V14	Maria Peel	Limburg	52 D	190.800	381.150	H Vs	Ia	birch	State Forest Service
V15	Deurnsche Peel - Grootvenbos	N. Brabant	52 C	189.500	381.400	H Vs	III	birch	State Forest Service
V17	Het Waal	Drenthe	7 C	228.400	577.200	H aVd	I	alder	State Forest Service

Nr	Location name	Province	Map	X coor	Y coor	Soil type		Water-table cl.	Species	Owner
V18	Beilen	Drenthe	17 B	230.700	540.900	H	hVc	II	alder	State Forest Service
V21	Fochteloërveen	Drenthe	12 C	227.800	557.750	H	aVs	Vbo	birch	*Natuurmonumenten*
V22	Nieuw Dordrecht	Drenthe	18 C	263.000	530.000	H	Vs	VIId	oak	State Forest Service
V25	Meddosche Veen	Gelderland	41 E	242.600	445.800	H	Vs	I	birch	City of Winterswijk
V26	Vragenderveen	Gelderland	41 E	241.500	444.500	H	Vs	IV	birch	*Marke Vragender*
V27	Vragenderveen	Gelderland	41 E	241.500	444.800	H	Vs	I	birch	*Marke Vragender*
V28	Haaksberger Veen	Overijssel	34 F	250.350	460.350	H	Vs	IIa	birch	State Forest Service
V30	Engbertdijksvenen	Overijssel	28 E	242.400	496.600	H	Vo	I	birch	State Forest Service
V34	Bargerveen	Drenthe	23 A	265.800	523.800	H	aVs	IV	birch	State Forest Service
V35	Schoonebeeker Veld - e.	Drenthe	23 A	264.900	520.600	H	aVs	IIb	birch	State Forest Service
V36	Barger Oosterveld	Drenthe	18 C	263.000	532.200	H	aVs	VIo	oak	State Forest Service
V37	Deurnsche Peel	N. Brabant	52 D	190.200	381.000	H	Vs	III	birch	State Forest Service
V38	Maria Peel	Limburg	52 D	192.800	380.450	H	Vs	IIIb	birch	State Forest Service
V39	Weerribben - Venebosch	Overijssel	16 D	192.150	535.100	L	Vc	I	birch	State Forest Service
V40	Weerribben - Stobbenribben	Overijssel	16 D	195.150	533.400	L	Vc	Ia	birch	State Forest Service
V41	Weerribben - Woldlakebos	Overijssel	16 D	196.650	532.500	L	Vc	Ia	birch	State Forest Service
V42	Engbertsdijksvenen - Schipsloot	Overijssel	28 E	241.250	499.700	H	Vs*F*	IIIb	birch	State Forest Service

Annex C Variation in the estimated results for the layer 0-30 cm and comparison with the results for the sandy soils.

Table C.1 Minimum, maximum, 5th, 50th and 95th percentiles of the estimations of the chemical characteristics in the 0-30 top layer of the loess, clay and peat soils, compared with the results for the sandy soils (cf. de Vries & Leeters, 1999)

	O.M. ($g\ kg^{-1}$)	Bulk den. ($kg\ m^{-3}$)	O.M.pool ($ton\ ha^{-1}\ 30cm^{-1}$)	C cont. (% of O.M.)	N cont. (% of O.M.)	P cont. (% of O.M.)	C/N ($g\ g^{-1}$)	C/P ($g\ g^{-1}$)	N/P ($g\ g^{-1}$)	C pool ($ton\ ha^{-1}\ 30cm^{-1}$)	N pool ($ton\ ha^{-1}\ 30cm^{-1}$)	P pool ($ton\ ha^{-1}\ 30cm^{-1}$)	$pH(H_2O)$ (-)	pH(KCl) (-)
<u>*Sandy soil (De Vries & Leeters, 1999):*</u>														
Minimum	7.0	150	34	25.71	1.27	0.07	10.2	13.4	0.8	8.6	0.58	0.10	3.4	2.6
5th percentile	9.0	1203	43	31.11	1.52	0.12	13.1	41.2	2.8	15.8	0.95	0.18	3.7	3.1
50th percentile	37.5	1393	158	42.46	2.03	0.29	20.3	150.6	7.3	69.0	3.11	0.36	4.1	3.6
95th percentile	76.0	1592	275	51.80	2.97	1.06	28.4	360.8	15.7	131.0	6.87	1.52	4.8	4.1
Maximum	790.0	1608	466	59.57	4.07	3.34	33.7	536.9	21.1	199.0	8.55	4.47	7.5	7.5
<u>*Loess soils:*</u>														
Minimum	20.1	1323	90	39.04	1.84	0.27	10.3	24.7	2.1	38.5	2.31	0.41	3.9	3.2
5th percentile	22.8	1397	104	41.69	1.95	0.28	11.7	28.9	2.3	51.4	2.59	0.47	3.9	3.3
50th percentile	44.4	1490	197	49.44	2.86	0.93	17.1	56.6	3.7	97.2	5.81	1.43	4.2	3.8
95th percentile	91.3	1527	413	57.83	4.48	1.84	27.5	186.6	7.8	185.5	12.63	3.84	5.9	5.0
Maximum	119.7	1531	547	62.08	5.28	2.71	29.1	230.2	8.6	293.7	18.04	4.68	6.9	6.8
<u>*Clay soils:*</u>														
Mininmum	21.1	1184	95	42.56	1.65	0.59	8.4	11.0	1.0	44.5	3.44	1.16	4.2	3.4
5th percentile	28.8	1194	124	43.27	3.74	0.87	9.0	13.8	1.3	56.4	5.50	1.81	4.5	3.4
50th percentile	58.7	1283	215	45.97	4.64	1.41	9.9	33.9	3.1	100.1	10.21	2.77	5.8	4.6
95th percentile	109.8	1440	448	49.91	5.21	3.96	12.6	52.1	5.2	194.6	14.07	5.74	7.2	6.8
Maximum	188.6	1498	689	50.45	5.51	4.36	30.1	86.7	5.5	335.7	16.66	9.65	7.4	6.9
<u>*Peat soils:*</u>														
Minimum	147.2	157	191	42.02	1.18	0.02	11.7	121.9	8.3	107.8	5.36	0.10	3.3	2.3
5th percentile	336.4	157	310	42.80	1.27	0.03	12.5	127.7	10.9	166.6	5.76	0.13	3.4	2.4
50th percentile	905.6	167	452	48.36	1.69	0.06	30.5	894.0	34.2	210.7	7.04	0.27	3.7	2.9
95th percentile	964.5	307	455	56.30	3.69	0.38	40.4	2053.8	53.2	235.5	15.49	0.90	4.8	3.8
Maximum	968.7	433	456	56.97	4.12	0.47	45.4	2082.5	57.9	239.8	17.97	1.68	5.8	5.2

Table C.1 (continued)

	CEC (mmol$_c$ kg^{-1})	CEC of OS (mmol$_c$ kg^{-1})	CEC OS$_{pH=6.5}$ (mmol$_c$ kg^{-1})	CEC pool (kmol$_c$ ha^{-1} 30cm^{-1})	H$_{exch.}$ (% of CEC)	Al$_{exch.}$ (% of CEC)	B.C.$_{exch.}$ (% of CEC)	Al$_{ox}$ (mmol$_c$ kg^{-1})	Fe$_{ox}$ (mmol$_c$ kg^{-1})	P$_{ox}$ (mmol$_c$ kg^{-1})	P$_{ox}$/P$_{tot}$ (%)	P$_{ox}$/(Al+Fe)$_{ox}$ (-)	Al$_{ox}$ pool (kmol$_c$ ha^{-1} 30cm^{-1})	Fe$_{ox}$ pool (kmol$_c$ ha^{-1} 30cm^{-1})	P$_{ox}$ pool (kmol$_c$ ha^{-1} 30cm^{-1})
<u>Sandy soil (De Vries & Leeters, 1999):</u>															
Minimum	6.0	363	813	29	0.0	0.0	1.4	7.7	2.1	0.1	14.2	0.013	37.0	7.8	0.5
5th percentile	10.0	568	1083	48	4.4	27.6	3.0	40.8	8.4	0.7	36.9	0.016	176.1	36.0	3.0
50th percentile	33.0	845	1532	135	21.0	65.6	6.4	108.8	30.3	1.7	56.8	0.034	446.7	133.9	6.6
95th percentile	74.0	1471	2699	279	46.0	78.9	35.5	214.5	121.0	10.5	86.1	0.180	760.2	489.3	39.8
Maximum	287.0	3833	5353	437	55.7	83.0	99.5	289.1	182.1	32.3	100.0	0.395	1077.0	727.8	120.0
<u>Loess soils:</u>															
Minimum	22.5	337	592	98	0.1	0.0	5.0	47.0	46.2	0.9	26.3	0.007	186.6	197.4	3.8
5th percentile	26.6	367	635	120	6.2	0.4	5.7	88.4	59.3	1.2	27.1	0.015	388.2	245.2	4.8
50th percentile	48.4	453	800	213	12.7	62.3	11.7	161.6	176.9	5.1	45.5	0.045	694.7	779.7	22.3
95th percentile	166.8	756	978	728	22.9	75.0	88.7	253.7	636.0	16.5	72.1	0.135	1137.5	2897.9	73.7
Maximum	223.0	1003	1015	1010	24.3	75.0	99.5	286.0	1011.0	23.3	77.0	0.154	1302.2	4578.9	106.5
<u>Clay soils:</u>															
Mininmum	70.4	548	1054	297	0.0	0.0	18.6	118.7	166.7	2.0	20.5	0.016	437.5	749.0	8.9
5th percentile	81.3	575	1058	317	0.0	0.0	25.2	119.7	225.9	4.9	21.1	0.017	533.3	949.5	18.3
50th percentile	272.8	783	1109	1067	9.7	0.9	85.0	212.0	449.5	7.9	36.8	0.040	854.1	1758.3	30.9
95th percentile	437.9	1170	1147	1600	22.6	36.2	99.8	342.0	891.9	28.0	69.0	0.138	1253.4	3591.7	110.9
Maximum	439.8	1216	1155	1605	30.2	37.7	99.9	377.7	959.6	55.0	69.5	0.163	1411.1	3637.0	214.6
<u>Peat soils:</u>															
Minimum	128.4	378	829	56	8.7	0.0	19.5	56.6	31.8	0.4	5.2	0.012	27.0	15.2	0.2
5th percentile	195.7	410	946	57	10.4	2.1	20.4	56.7	36.4	0.8	7.4	0.012	27.6	17.4	0.4
50th percentile	409.5	458	1163	68	36.6	8.0	40.2	142.4	76.4	1.9	15.2	0.026	71.5	37.8	1.1
95th percentile	631.7	875	1494	109	66.1	30.0	70.9	574.7	650.9	16.9	44.6	0.079	351.1	844.9	14.1
Maximum	1058.2	1426	1793	207	66.5	30.4	89.9	605.7	1676.7	41.3	51.8	0.107	416.7	985.9	24.3

Table C.1 (continued)

	pH (-)	cSi ($mol_c m^{-3}$)	cCa ($mol_c m^{-3}$)	cMg ($mol_c m^{-3}$)	cK ($mol_c m^{-3}$)	cNa ($mol_c m^{-3}$)	cAl ($mol_c m^{-3}$)	cFe ($mol_c m^{-3}$)	cMn ($mol_c m^{-3}$)	cNH4 ($mol_c m^{-3}$)	cNO3 ($mol_c m^{-3}$)	cSO4 ($mol_c m^{-3}$)	cCl ($mol_c m^{-3}$)	cPO4 ($mol_c m^{-3}$)	cCOO ($mol_c m^{-3}$)
Sandy soil (De Vries & Leeters, 1999):															
Minimum	2.79	0.29	0.06	0.07	0.03	0.26	0.00	0.01	0.00	0.04	0.00	0.24	0.40	0.00	0.07
5th percentile	3.26	0.57	0.13	0.11	0.07	0.34	0.18	0.01	0.00	0.06	0.03	0.39	0.55	0.00	0.11
50th percentile	3.61	1.17	0.44	0.25	0.20	0.77	0.63	0.02	0.01	0.18	0.54	0.98	1.30	0.00	0.19
95th percentile	4.30	2.62	2.34	0.74	0.60	2.55	1.82	0.08	0.07	1.11	1.76	3.22	2.76	0.06	0.54
Maximum	7.19	4.15	3.95	1.61	1.23	6.52	10.69	0.21	0.13	3.16	5.60	14.99	6.80	0.12	2.89
Loess soils:															
Minimum	3.48	0.54	0.24	0.04	0.08	0.09	0.03	0.01	0.00	0.02	0.06	0.34	0.10	0.00	0.12
5th percentile	3.64	0.69	0.25	0.10	0.09	0.10	0.09	0.01	0.00	0.03	0.16	0.37	0.14	0.00	0.13
50th percentile	4.00	1.50	0.67	0.22	0.14	0.32	0.29	0.02	0.04	0.06	1.14	0.77	0.27	0.00	0.20
95th percentile	5.95	2.63	2.60	0.61	0.29	0.91	1.08	0.13	0.15	0.26	2.50	1.59	0.64	0.02	0.38
Maximum	7.28	2.85	5.05	0.64	0.49	1.08	1.67	0.27	0.18	0.76	3.44	2.23	0.84	0.02	0.45
Clay soils:															
Mininmum	4.11	0.76	0.29	0.14	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.25	0.08	0.00	
5th percentile	4.13	1.11	0.39	0.18	0.01	0.17	0.00	0.01	0.00	0.00	0.04	0.28	0.09	0.00	
50th percentile	5.91	1.67	1.23	0.28	0.02	0.40	0.05	0.04	0.01	0.01	0.20	0.60	0.19	0.01	
95th percentile	7.08	3.13	2.61	0.42	0.05	0.95	0.23	0.14	0.11	0.05	0.71	1.40	0.44	0.06	
Maximum	7.13	3.52	2.65	0.42	0.08	1.02	0.31	0.15	0.14	0.07	0.72	1.51	0.46	0.10	
Peat soils:															
Minimum	3.19	0.16	0.14	0.08	0.03	0.23	0.01	0.01	0.00	0.05	0.00	0.21	0.42	0.00	0.16
5th percentile	3.19	0.17	0.14	0.10	0.03	0.25	0.01	0.02	0.00	0.07	0.00	0.29	0.45	0.01	0.16
50th percentile	3.68	0.37	0.36	0.23	0.12	0.51	0.10	0.04	0.00	0.22	0.18	0.66	0.91	0.04	0.23
95th percentile	4.51	1.38	2.18	0.54	0.69	2.25	0.20	0.18	0.05	0.86	1.23	1.55	3.15	0.16	0.40
Maximum	5.90	2.05	2.90	0.79	0.79	4.21	0.23	0.22	0.10	0.89	2.97	1.77	6.68	0.32	0.41

Table C.1 (continued)

	$\frac{NH_4}{NO_3}$ ($mol_c\ mol_c^{-1}$)	$\frac{NH_4}{K}$ ($mol_c\ mol_c^{-1}$)	$\frac{NH_4}{Mg}$ ($mol_c\ mol_c^{-1}$)	$\frac{Al}{Ca}$ ($mol\ mol^{-1}$)	$\frac{Al}{B.C.}$ ($mol\ mol^{-1}$)	$\frac{NH_4+NO_3}{SO_4}$ ($mol_c\ mol_c^{-1}$)	$\frac{H-Al}{NO_3+SO_4-NH_4}$ ($mol_c\ mol_c^{-1}$)
<u>*Sandy soil (De Vries & Leeters, 1999):*</u>							
Minimum	0.04	0.12	0.07	0.00	0.00	0.04	0.00
5th percentile	0.08	0.33	0.18	0.12	0.04	0.27	0.21
50th percentile	0.48	1.12	0.89	1.08	0.16	0.80	0.77
95th percentile	2.75	4.58	3.68	2.44	0.40	1.72	1.34
Maximum	6.79	17.45	7.36	8.98	0.47	2.49	1.67
<u>*Loess soils:*</u>							
Minimum	0.02	0.08	0.07	0.01	0.00	0.13	0.01
5th percentile	0.02	0.18	0.08	0.03	0.02	0.24	0.04
50th percentile	0.08	0.42	0.39	0.32	0.10	1.72	0.28
95th percentile	0.58	1.65	1.71	1.49	0.41	2.66	0.74
Maximum	1.04	2.20	2.49	1.80	0.49	3.61	0.78
<u>*Clay soils:*</u>							
Mininmum	0.00	0.01	0.00	0.00	0.00	0.01	0.00
5th percentile	0.00	0.02	0.00	0.00	0.00	0.09	0.00
50th percentile	0.02	0.45	0.02	0.02	0.01	0.41	0.05
95th percentile	1.98	8.86	0.23	0.47	0.10	0.75	0.47
Maximum	9.17	29.65	0.32	0.48	0.10	1.13	0.71
<u>*Peat soils:*</u>							
Minimum	0.04	0.13	0.21	0.00	0.00	0.16	-8.50
5th percentile	0.06	0.36	0.22	0.02	0.00	0.28	0.01
50th percentile	1.10	2.76	1.14	0.12	0.03	0.82	0.61
95th percentile	32.86	9.05	3.70	0.45	0.08	2.51	3.68
Maximum	39.28	12.37	4.36	0.47	0.09	4.45	4.01

Annex D Analysis of soil solution concentrations at a standardized Cl level

The concentrations of the various ions in the soil solution are subject to dilution or concentration, related to hydrological processes, such as interception, soil evaporation, seepage and water uptake by the vegetation. These effects can be accounted for by the use of Cl as a tracer. This ion is considered to be inert during its flow through the soil ecosystem. In order to investigate the effect of dilution/concentration on the outcome of the statistical analysis, also an analysis is made of the relationship between the variation in the Cl concentration and the available environmental characteristics (Table D.1). The characteristics that are related to the variation in the Cl concentration are more vulnerable to be influenced by dilution/ concentration processes. The possible impact of such dilution/concentration is estimated by giving the correlation coefficients for between the Cl concentration and the concentrations of the other ions for the separate layers and for the plot mean values (Table D.2). Finally, the statistical analysis of the concentrations of the various ion has been repeated, assuming that the same Cl concentration was found in all samples (Table D.3). This was done by analysing the concentrations relative to the Cl concentration in the same sample. These results can be compared with results of the regression on the original data (Table 102).

Statistical analysis of the Cl measurements showed that for loess and clays soils hardly any significant relatioship could be found with the environmental characteristics (Table D.1). FOr the loess soils only a relatioship with the soil type could be found in the subsoil. For the clay soils there seems to be a raltionship with the drainage class, in the topsoil combined with some characteristics related to the drying effect of a position close to the forest edge. For the peat soils the deposition of the various compound seems relavant, mostly combined with the soils type. This, however, is probably related to the influence of the Cl concentration in nearby surface water and ground water, especially in the west of the country.

Table D.1 Best explaining environmental characteristics for the Cl concentrations in the soil solution, retrieved by multiple regression analysis

Layer	Loess soils			Clay Soils			Peat soils		
	Factors	$\%R^2_{adj}$	Sign.	Factors	$\%R^2_{adj}$	Sign.	Factors	$\%R^2_{adj}$	Sign.
0-10 cm	Tr + Di	21	*	Dr + Dp_{so} + Ds + Di	64	**	Dp_{no}	46	***
10-30 cm	Di	14	*	Dr + Di	36	*	So + Dp_{so}	59	***
30-60 cm				Dr	28	*	So + Dp_{so} + Dpso.So	73	***
60-100 cm	So + Di	44	***	Dr	29	*	So + Dp_{so} + Dpso.So	74	***
Plot-means	Dr + Di	22	*	Dr	31	**	So + Dp_{so} + Ds	68	***

The results of the correlation exercise between the concentration of the various elements and the Cl concentration showed, that there were generally only few clear correlations (absolute coeffcient larger than 0.5 or even 0.8). More or less clear positive correlations were found for the SO_4 concentration in the loess soils and the subsoil of the clay soils. SO_4, like Cl, acts as a tracer in most of these soils. In the peat soils (and probably also in the wetter clay soils), however, SO_4 is due to various transformation related to the water logged conditions and the large amount of organic matter. Additionally, positive correlations were found for K in the loess soils, and for Ca in the deep subsoils of both loess and clay soils. Finally, the NH_4 concentration in the top layer of the loess soils is positively correlated with the Cl concentration. This might be related to correlations in the deposition, which effect disappears in deeper layers.

Table D.2 Correlation coefficients of the pH and the nutrient concentrations with the Cl concentration in the soil solution

Layer	pH	Ca	K	Al	NH_4	NO_3	SO_4
Loess soils:							
0 - 10 cm	-0.12	0.08	0.80	0.34	0.50	-0.24	0.61
10 - 30 cm	0.10	0.40	0.84	0.11	-0.06	-0.01	0.76
30 - 60 cm							
60 - 100 cm	0.38	0.66	0.85	-0.03	-0.12	-0.06	0.88
Plot-mean values	0.17	0.44	0.91	0.20	0.10	-0.12	0.84
Clay soils:							
0 - 10 cm	0.29	0.45	-0.16	-0.27	-0.28	-0.01	0.46
10 - 30 cm	0.26	0.29	-0.31	-0.16	-0.11	-0.03	0.28
30 - 60 cm	-0.03	0.36	0.34	-0.30	-0.07	-0.21	0.72
60 - 100 cm	0.04	0.56	0.26	-0.11	-0.11	-0.09	0.85
Plot-mean values	-0.03	0.32	0.17	-0.32	-0.07	0.20	0.59
Peat soils:							
0 - 10 cm	-0.06	0.22	0.40	0.13	0.15	0.25	0.37
10 - 30 cm	0.18	0.16	0.10	0.08	0.10	-0.13	0.08
30 - 60 cm	0.38	0.34	0.21	0.01	0.09	-0.13	-0.13
60 - 100 cm	0.50	0.39	0.33	0.06	0.02	-0.02	0.05
Plot-mean values	0.56	0.41	0.42	-0.04	0.32	-0.21	-0.23

The poor correlations found in Table D.2 are the main reason that the results of the statistical analysis for the various elements after correction for the variation in the Cl concentration, hardly showed any improvement compared to the analysiis of the original values (Section 6.3.5). The resulting models and the percentage of variance accounted for, were generally comparable with the results for the original values (Table D.3; compare with Section 6.3.5). Most changes were not related to the main elements of each model, but with characterics which were include at the end of the selction model, which only contribute marginally ot the variance accounted for, and which could easily be relaced by different predictors.

Table D.3 Best explaining environmental characteristics for the Cl-corrected pH and nutrient concentrations, retrieved by multiple regression analysis

Analysed variable	Simple model [1]			Full model [2]		
	Factors	$\%R^2_{adj}$	Sign.[3]	Factors	$\%R^2_{adj}$	Sign.[3]
Loess soils: [4]						
pH	So + Tr	46	***	So + Tr + Dp_t + La	68	***
Ca	So + Dr + Tr	50	***	So + Dr + Tr + Dp_t + He	69	***
K	So	13	*	Dp_{no} + Di	29	**
Al	So + Tr	50	***	Tr + Dp_t	58	***
NH_4	So + Dr	28	**	Dr + Ds + Dp_{nh}	48	***
NO_3	So + Dr + Tr	12	-	Dr	7	*
SO_4	So + Dr + Tr	24	*	So + Dr + Tr	24	*
Clay soils:						
pH	So + Dr	37	**	So + Dr + Dp_{so} + Dp_{so}.So	58	***
Ca	So + Dr	28	*	So + Dr	28	*
K	Dr	2	-	Dp_{nh} + Dr_c.Dp_{nh}	10	*
Al	So + Dr + Tr	59	***	So + Dr + Tr + Ds	67	***
NH_4	So + Tr	27	*	So + Di	45	**
NO_3	Dr	10	*	Dr	10	*
SO_4	So + Dr	5	-	Dp_{so} + Di	22	*
Peat soils:						
pH	So + Dr + Tr	69	***	Dr + Tr + Dp_{no} + Di + Dr_c.Dp_{no}	86	***
Ca	So + Tr	29	**	So	28	**
K	Dr + Tr	24	*	Dr + Tr + Ds	48	***
Al	So + Dr + Tr	66	***	So + Dr + Dp_{so} + Dp_{so}.Dr	82	***
NH_4	So + Dr + Tr	37	**	So + Tr	36	**
NO_3	So + Dr + Tr	46	***	Dr + He + Ds_w	62	***
SO_4	So	55	***	Ds_w	65	***

[1] Simple model: analysis only with 'Soil Type', 'Drainage Class' and 'Tree Species' (coding cf. Section 2.4).

[2] Full model: with all environmental characteristics (coding and hierarchic ordering cf. Section 2.4).

[3] Significance: - = ($p \geq 0.1$), * = ($p<0.1$), ** = ($p<0.01$), *** = ($p<0.001$)

[4] Data for loess soils based on layers 0-10 cm, 10-30 cm and 60-100 cm only.

Annex E Results of the statistical analysis for the layers separately.

Table E.1 Results of the statistical analyses for all layers separately with explained variance by the soil type, the drainage class, the tree species and the 'best' explaining model; the results for the humus layer (hum.) and the plot-mean values (loc., including all mineral layers) are added for comparison; selected elements from the simple model are printed in ***bold***

Variable	Layer	Loess soils						Clay soils						Peat soils					
		Soil	Drain.	Spec.	Best Model	$\%R^2_{adj}$	Sign.	Soil	Drain.	Spec.	Best Model	$\%R^2_{adj}$	Sign.	Soil	Drain.	Spec.	Best Model	$\%R^2_{adj}$	Sign.
Organic matter content (g kg^{-1})	hum.	0.0	0.6	0.0	-	0.0	-							5.2	22.3	0.0	-	0.0	-
	1	0.0	4.2	0.0	**Dr**+Di+Dr.Dp$_{so}$+He	51.5	***	2.4	13.7	15.2	**Dr**+Di	35.4	**	13.4	0.0	2.3	**So**+Dp$_{no}$	24.9	*
	2	0.0	13.1	19.3	**Dr**+Di	23.4	**	0.0	7.9	23.2	**Dr**$_c$+Di+Ca	43.0	***	33.8	6.3	13.7	**So**	33.8	**
	3	2.5	0.0	16.4	Dp$_{nh}$	24.3	***	0.0	0.0	10.3	Ca+Di	29.9	**	61.7	24.3	19.3	**So**+**Dr**$_c$	65.2	***
	4	8.7	6.4	11.2	Ca	16.1	**	0.0	30.2	28.8	**Dr**$_c$+Ca+Dp$_t$+Dr$_c$.Dp$_t$	57.6	***	23.9	25.0	4.1	**So**+**Dr**$_c$	39.5	**
	loc.	2.9	8.3	19.7	**Dr**+Ca+Dp$_{nh}$.Dr	43.6	***	0.0	16.0	26.8	**Dr**$_c$+Di+Ca	44.2	***	39.8	12.0	12.8	**So**+**Dr**$_c$	43.9	***
Bulk density (kg m^{-3})	hum.	2.6	0.0	0.0	Dp$_t$+He+Ds	38.4	***							4.7	22.0	0.0	-	0.0	-
	1	14.9	0.0	0.0	**So**+Di+Dp$_n$.So	67.2	***	1.1	7.3	17.7	**Dr**$_c$+Di	18.5	*	9.7	0.0	4.8	**So**	9.7	*
	2	54.6	0.0	0.0	**So**+Di+Dp$_{no}$+Dp$_{no}$.S	80.3	***	13.1	43.0	7.7	**Dr**	43.0	***	12.2	0.0	8.3	**So**+La$_2$	46.0	**
	3	65.9	0.0	0.0	**So**	65.9	***	44.6	44.0	3.8	**So**+**Dr**+Ds	78.8	***	43.8	15.0	16.6	**So**+La$_2$+Tr+Ds	78.6	***
	4	0.0	0.0	0.0	-	0.0	-	40.7	45.3	7.3	**So**+**Dr**$_c$+Ds	88.0	***	20.0	20.1	8.2	**So**+**Dr**	36.1	**
	loc.	34.8	0.0	0.0	**So**+Dp$_{so}$.So	57.7	***	28.5	43.3	14.4	**So**+**Dr**	56.4	***	21.0	3.4	10.9	**So**	21.0	*
Organic matter pool (tons ha^{-1})	hum.	21.9	0.0	16.6	Dp$_t$+Ds+He	53.3	***							13.3	20.8	9.1	**So**+La+Dp$_{so}$.So	57.8	***
	1	0.0	4.2	0.9	**Dr**+Di+Dp$_{so}$.Dr+He	52.4	***	2.8	15.0	12.6	**Dr**$_c$+Di	36.4	***	4.3	0.0	6.5	-	0.0	-
	2	1.3	12.4	18.7	**Dr**	12.4	*	0.0	4.4	22.4	**Dr**$_c$+Di+Ca	42.7	***	0.0	0.0	3.0	-	0.0	-
	3	3.4	0.0	16.0	Dp$_{nh}$	24.5	***	0.0	0.0	6.9	Ca+Di	29.6	**	18.7	4.6	4.5	**So**+La$_2$	72.3	***
	4	8.7	6.4	11.1	Ca	16.0	**	0.0	21.6	25.6	**Dr**$_c$	24.4	**	9.1	6.3	12.9	**So**+**Dr**	19.1	*
	loc.	2.8	9.4	18.5	**Dr**+Ca+Dp$_{nh}$.Dr+Di	46.1	***	0.0	11.3	23.9	**Dr**$_c$+Ca+Di	41.0	***	6.7	0.0	1.4	**So**+La$_2$	62.8	***
C content (% O.M.)	hum.	0.4	6.1	4.9	-	0.0	-							0.0	0.0	0.0	Dp$_{nh}$+Di	42.6	***
	1	12.8	8.0	0.0	**So**+Ds+He	33.0	**	0.0	11.4	1.5	**Dr**$_c$+Di+Ca+Dp$_{so}$	55.1	***	0.0	0.0	3.2	Di+Dp$_n$	24.8	**
	2	8.8	2.7	0.0	Di	13.5	*	0.0	3.8	0.0	**Dr**$_c$+Di	22.9	*	5.7	0.0	0.0	-	0.0	-
	3							0.0	0.0	0.0	Ds	19.8	**	1.7	0.0	0.0	-	0.0	-
	4							0.0	0.0	0.7	Ds	27.3	**	0.0	0.0	0.0	Di+He	22.2	*
	loc.	14.5	5.4	0.5	**So**+Di	27.4	**	0.0	0.0	0.0	Ds	30.9	***	0.0	0.0	0.0	-	0.0	-
N content (% O.M.)	hum.	0.0	0.0	0.0	La	24.4	**							14.2	16.4	0.0	**So**	14.2	*
	1	20.4	0.0	16.0	**So**+Dp$_t$	37.6	***	30.5	28.1	1.4	**So**+**Dr**+Ca+Dp$_{no}$.So	80.3	***	33.7	3.3	1.2	**So**+**Dr**$_c$+Dp$_{no}$	57.1	***
	2	18.3	0.0	11.8	**So**+**Dr**+Dp$_t$+Ds	47.0	***	27.2	11.2	0.0	**So**+Ca	45.2	***	50.4	25.1	14.7	**So**+**Dr**$_c$+Dp$_{no}$	65.0	***
	3	12.8	0.0	22.7	**So**+Ca+Tr+Dp$_{nh}$	65.5	***	12.7	1.6	0.0	**So**+Ca+Ds	36.8	**	59.9	31.4	13.7	**So**+**Dr**$_c$+Dp$_{no}$	75.2	***
	4	5.1	0.0	23.1	Ca	26.1	***	1.9	0.0	0.9	Ds	15.7	*	48.9	39.2	5.5	**So**+**Dr**	67.3	***
	loc.	24.1	0.0	23.4	Tr+Dp$_{no}$+He	60.3	***	22.3	6.9	0.0	**So**+Ca+Ds	46.9	***	51.9	28.4	10.2	**So**+**Dr**$_c$+Di+Dp$_{no}$	75.1	***

Table E.1 (continued)

Variable	Layer	Loess soils						Clay soils						Peat soils					
		Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.
P content	hum.	16.7	0.0	28.1	**Tr**+Dp$_t$+He	52.4	***							26.7	17.1	6.2	**So**+**Tr**	46.5	***
(% O.M.)	1	1.5	0.0	4.7	Dp$_{no}$+He	22.6	**	0.0	0.0	5.6	-	0.0	-	21.1	0.0	6.2	**So**+Dp$_{no}$	41.2	***
	2	0.0	3.9	0.0	**Dr**+Di+Dp$_{no}$	28.4	**	0.0	1.2	25.1	Tr+He	37.7	**	28.3	9.1	17.5	**Dr**$_c$+Dp$_{no}$	44.3	***
	3	0.0	0.0	2.1	Ca	13.8	*	0.0	0.0	13.1	Ca+Di	25.9	**	49.0	19.8	21.7	**So**+**Dr**$_c$	55.1	***
	4	0.0	7.6	0.0	**Dr**	7.6	*	0.0	7.2	13.6	**Dr**$_c$+Ca	22.5	*	37.9	21.2	11.0	**So**+**Dr**$_c$+Tr	60.9	***
	loc.	0.0	3.9	0.0	**Dr**+Dp$_{no}$	11.4	*	0.0	1.1	18.1	**Dr**$_c$	4.3	-	35.9	9.9	14.7	**So**+**Dr**$_c$+Dp$_{no}$	54.9	***
C/N ratio	hum.	0.0	5.8	7.0	La	37.2	***							7.6	13.6	0.0	Dr$_c$	15.1	*
(g g^{-1})	1	14.5	0.0	12.4	**So**+**Dr**+Dp$_t$	41.8	***	27.8	30.4	2.9	**So**+**Dr**+Ca+Dp$_{no}$	78.8	***	26.9	2.0	5.0	**So**+**Dr**$_c$+Dp$_{no}$	50.6	***
	2	9.8	0.0	9.2	**So**+**Dr**+Dp$_t$+Tr	53.5	***	26.9	14.0	0.0	**So**+**Dr**$_c$+Ca	53.0	***	52.3	30.5	12.4	**So**+**Dr**$_c$+Dp$_{no}$	68.0	***
	3							20.0	2.1	0.0	**So**+Ca	37.3	**	57.0	31.3	11.9	**So**+**Dr**$_c$+Dp$_{no}$	74.1	***
	4							0.8	0.0	0.0	-	0.0	-	50.2	35.3	5.5	**So**+**Dr**+Di	72.5	***
	loc.	12.5	0.0	11.4	**So**+**Dr**+Dp$_t$+Tr	57.1	***	23.9	10.2	0.0	**So**+**Dr**$_c$+Ca+Dp$_{no}$, So+Dr$_c$.Dp$_{no}$	72.5	***	49.7	27.9	10.0	**So**+**Dr**$_c$+Dp$_{no}$	70.0	***
C/P ratio	hum.	16.0	0.0	32.3	**Tr**+Dp$_t$+La+He	68.2	***							25.6	18.5	5.2	**So**+**Tr**	43.9	**
(g g^{-1})	1	0.0	0.5	4.0	Dp$_t$	18.7	**	0.0	0.0	4.8	Di	18.5	*	19.5	0.0	7.4	**So**+Dp$_{no}$	39.6	**
	2	0.0	6.0	0.0	**Dr**+Di+Dp$_{no}$	19.9	**	0.0	0.0	25.4	Tr+He	16.9	**	29.9	12.0	17.6	**Dr**$_c$+Dp$_{no}$	49.2	***
	3							0.0	0.0	13.7	Ca+Di	27.1	**	48.0	19.9	20.7	**So**+**Dr**$_c$	54.3	***
	4							0.0	9.3	14.4	**Dr**$_c$+Ca	28.6	**	38.7	19.4	10.2	**So**+**Dr**$_c$+Tr	58.4	***
	loc.	0.0	5.2	0.0	**Dr**+Dp$_{no}$+Di	30.6	**	0.0	1.0	18.3	**Dr**$_c$+Ca	17.4	*	35.1	10.0	14.8	**So**+**Dr**$_c$+Dp$_{no}$	54.9	***
N/P ratio	hum.	27.4	0.5	26.7	**So**+**Tr**+Dp$_t$	51.4	***							27.2	5.8	3.1	**So**+**Tr**+La	70.0	***
(g g^{-1})	1	0.0	1.9	0.0	-	0.0	-	9.7	8.1	13.6	**Dr**$_c$	11.1	*	16.0	0.0	9.1	**So**	16.0	*
	2	0.0	9.4	0.0	**Dr**+Di	19.9	**	8.8	15.7	28.2	**Dr**$_c$	17.7	*	10.6	0.0	16.0	**So**	10.6	**
	3	0.0	0.0	8.9	Ca	24.1	***	8.4	5.0	16.8	**So**+Tr+He+**Dr**	71.1	***	26.5	3.5	26.0	**So**+Tr	43.9	**
	4	0.0	7.6	0.0	**Dr**	7.6	*	0.0	12.9	13.8	**Dr**$_c$+Ca+He	43.1	***	11.5	0.0	20.2	**So**+Tr+Ca	53.1	***
	loc.	0.0	5.6	0.0	**Dr**+Ca	15.1	*	6.5	12.7	22.2	He+Tr	51.5	***	16.5	0.0	17.8	**So**	16.5	*
C pool	hum.	20.5	0.0	16.8	Dp$_t$+Ds+He	52.1	***							11.7	20.2	9.2	**So**+La+Dp$_{so}$.So	56.8	***
(kg ha^{-1})	1	0.0	8.0	2.6	**Dr**+Di+Ds+Dp$_{so}$.So+Ca	51.1	***	2.7	12.6	11.5	**Dr**$_c$+Di	30.7	**	0.0	0.0	7.7	-	0.0	-
	2	2.2	16.5	18.4	**So**+Di	27.2	**	0.0	2.7	22.0	Di	28.3	**	0.0	0.0	4.5	-	0.0	-
	3							1.0	0.0	5.7	Ca	22.2	**	13.3	4.9	1.7	**So**+La$_2$+Ca+Di	73.5	***
	4							0.0	25.8	25.9	**Dr**$_c$+Ca+Dp$_t$+Dr$_c$.Dp$_t$	55.2	***	0.0	0.0	0.0	Di	18.4	*
	loc.	2.8	18.1	19.9	**Dr**+Di	28.4	***	0.0	10.7	22.5	**Dr**$_c$+Ca+Di	40.2	***	4.0	0.0	1.9	-	0.0	-

Table E.1 (continued)

Variable	Layer	Loess soils						Clay soils						Peat soils					
		Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.
N pool	hum.	23.5	0.6	14.6	Dp$_{nh}$+Ds	49.0	***							12.1	21.2	9.1	**So**+La+Dp$_{so}$.So	57.4	***
(kg ha^{-1})	1	10.6	4.8	25.7	Tr	25.7	**	8.3	43.6	24.5	**Dr**$_c$+Di	55.0	***	33.6	14.2	0.0	**So**+Dp$_{no}$	46.4	***
	2	16.2	8.3	40.3	Tr+Dp$_{no}$	51.3	***	0.0	32.4	32.6	**Dr**+Di	51.2	**	51.3	30.9	6.5	**So**+**Dr**$_c$+Dp$_{no}$	67.4	***
	3	5.1	0.0	24.3	Tr+Dp$_n$	34.7	***	0.0	10.0	13.8	**Dr**$_c$+Ca	27.5	**	53.2	28.8	10.2	**So**+**Dr**$_c$+Dp$_{no}$+Di+Dr$_c$.Dp$_n$	83.5	***
	4	9.0	6.0	14.1	Ca	44.7	***	0.0	37.9	27.6	**Dr**$_c$+Ca+Dp$_t$+Dr$_c$.Dp$_t$	65.2	***	51.6	41.2	4.7	**So**+**Dr**$_c$+Di	74.1	***
	loc.	14.0	6.9	33.9	Tr+Ca	43.6	***	0.0	41.1	35.1	**Dr**$_c$+Di+Ca	55.4	***	51.5	33.5	7.5	**So**+**Dr**+Dp$_{no}$	75.3	***
P pool	hum.	12.6	0.0	4.9	Dp$_t$+Ds	35.8	***							9.7	21.4	9.6	**So**+La+Dp$_{so}$.So	54.9	***
(kg ha^{-1})	1	4.4	0.0	23.3	Tr+Dp$_{no}$	34.4	***	0.0	0.0	0.0	-	0.0	-	19.3	0.0	3.3	Dp$_{no}$	35.1	***
	2	9.2	0.0	23.2	**So**	9.2	*	0.0	0.0	0.0	-	0.0	-	30.9	12.1	10.3	**Dr**$_c$+Dp$_{no}$	52.6	***
	3	0.0	0.0	6.3	Dp$_t$+Ca	17.6	*	9.1	0.0	0.0	**So**	9.1	-	47.3	18.9	21.4	Dp$_{no}$+Tr+He	73.7	***
	4	10.7	0.0	6.0	Dp$_n$	23.0	**	0.0	0.0	0.0	He	35.7	***	39.4	21.8	10.6	**So**+**Dr**$_c$+Tr	62.2	***
	loc.	1.2	0.0	0.0	Dp$_t$	14.5	**	0.2	0.0	0.0	He	18.2	*	36.9	10.7	13.4	**So**+**Dr**$_c$+Dp$_{no}$	57.7	***
pH(H_2O)	hum.	30.1	1.6	34.4	**Tr**+Dp$_t$+He+Ds	67.0	***							18.5	0.0	0.0	**So**	18.5	*
	1	19.5	0.0	7.9	**So**+Dp$_t$	46.0	***	35.3	6.1	23.4	**So**+**Dr**$_c$	46.6	***	10.3	0.0	19.2	**So**+**Dr**$_c$+La$_2$	48.3	**
	2	24.6	0.0	10.2	**So**+Dp$_t$	45.3	***	37.4	7.0	12.0	**So**+**Dr**$_c$+Dp$_{nh}$.So+Di	76.8	***	10.6	8.3	22.8	**So**+**Dr**+Dp$_{no}$.So	50.4	***
	3	38.4	4.5	23.1	**So**+Dp$_t$	53.2	***	28.7	13.6	13.4	**So**+**Dr**+Dp$_{so}$	54.9	***	34.4	22.6	26.0	**So**+Dp$_{no}$.So	61.7	***
	4	40.1	3.6	33.6	**So**+Dp$_t$	54.8	***	18.1	4.4	0.0	**So**+Dp$_{so}$	33.0	**	41.0	32.2	14.4	**So**+**Dr**$_c$+Tr+Dp$_t$+Dr$_c$.Dp$_t$	81.8	***
	loc.	33.0	1.5	19.6	**So**+Dp$_t$	52.9	***	37.0	7.4	13.7	**So**+**Dr**+Dp$_{so}$	57.2	***	25.6	20.5	27.5	**So**+**Dr**$_c$+Dp$_{no}$.So	61.6	***
pH(KCl)	hum.	35.8	1.9	37.9	**Tr**+Dp$_t$+He+Ds	71.2	***							23.5	0.0	0.0	**So**	23.5	*
	1	17.9	0.0	3.9	**So**+Dp$_t$+La	56.8	***	44.3	0.0	21.1	**So**+**Dr**	51.6	***	7.0	6.5	13.8	**So**+**Dr**$_c$+La$_2$+Dp$_{no}$.S	63.6	***
	2	12.7	0.0	0.0	**So**+Dp$_n$.So	50.7	***	45.1	3.8	12.9	**So**+**Dr**	58.6	***	16.8	12.5	18.5	**So**+**Dr**$_c$+La+Dp$_{no}$.So	68.1	***
	3	32.1	0.8	9.7	**So**+Dp$_{no}$.So	50.5	***	27.2	7.9	12.9	**So**+**Dr**+Dp$_{so}$	54.6	***	43.1	31.6	19.7	**So**+**Dr**$_c$+Dp$_{no}$	73.4	***
	4	35.0	4.5	20.3	**So**+Dp$_{so}$.So	52.4	***	12.5	0.7	0.0	**So**+Dp$_{no}$	32.7	**	48.7	29.8	13.1	**So**+**Dr**$_c$+Tr+Dp$_t$.Dr	85.5	***
	loc.	27.6	0.0	8.7	**So**+Dp$_{so}$+La	55.7	***	40.2	2.4	13.1	**So**+**Dr**+Dp$_{so}$	60.8	***	34.0	27.3	22.6	**So**+**Dr**$_c$+Dp$_{no}$.So	70.2	***
CEC	hum.	4.4	0.7	20.9	**Tr**+He	28.8	***							1.4	13.3	0.0	-	0.0	-
(mmol$_c$ kg^{-1})	1	25.6	2.9	18.3	**So**	25.6	**	33.0	43.0	15.9	**So**+**Dr**$_c$	62.0	***	0.0	0.5	0.0	-	0.0	-
	2	36.1	4.8	20.4	**So**+Dp$_n$	47.9	***	40.4	34.5	5.4	**So**+**Dr**$_c$+Dp$_{so}$.So+Ca	76.8	***	3.2	0.0	0.9	-	0.0	-
	3	43.5	2.6	13.8	**So**+Dp$_t$	55.4	***	51.0	26.1	2.3	**So**+**Dr**$_c$+Dp$_{so}$+Dp$_{so}$.So	76.5	***	0.0	0.0	0.9	He	10.1	*
	4	44.9	1.7	15.4	**So**+Dp$_n$	49.8	***	46.9	18.4	0.0	**So**+**Dr**$_c$+Dp$_{no}$+Dp$_{no}$.So	80.0	***	22.6	6.7	7.4	**So**	22.6	*
	loc.	43.2	3.7	19.5	**So**+Dp$_n$	53.0	***	46.6	32.8	5.9	**So**+**Dr**$_c$+Dp$_{so}$+Dp$_{so}$.So	78.0	***	0.0	1.9	0.0	-	0.0	-

Table E.1 (continued)

Variable	Layer	Loess soils Soil	Drain.	Spec.	Best Model	$\%R^2_{adj}$	Sign.	Clay soils Soil	Drain.	Spec.	Best Model	$\%R^2_{adj}$	Sign.	Peat soils Soil	Drain.	Spec.	Best Model	$\%R^2_{adj}$	Sign.
CEC in	hum.	12.6	0.0	24.9	**Tr**+Dp_{t}+He	51.8	***							2.4	15.7	0.0	-	0.0	-
O.M.	1	18.2	0.0	4.1	**So**+Dp_{t}+La	56.6	***							10.4	0.0	5.3	**Dr_{c}**+Dp_{no}.So	46.5	***
($mmol_c\ kg^{-1}$)	2	15.4	0.0	3.0	**So**+Dp_{nh}.So+Tr	62.1	**							4.4	0.0	7.2	**So**+**Dr_{c}**+La	40.4	**
	3	43.4	0.0	11.7	**So**+Dp_{t}	56.7	***							26.8	21.9	17.2	**So**+**Dr_{c}**	35.7	**
	4	20.6	0.2	22.6	**So**	20.6	*							27.6	10.7	11.3	**Dr_{c}**+Di+Dp_{no}	56.8	***
	loc.	29.3	0.0	15.2	**So**+Dp_{n}+La	52.5	***							14.6	8.4	15.2	**So**+**Dr_{c}**+Dp_{no}.So+	***	
CEC in	hum.	6.6	4.2	0.0	-	0.0	-							0.0	12.1	0.0	Dr_{c}	16.0	*
O.M.,	1	15.5	0.0	3.4	**So**+**Dr**	18.1	*							22.7	0.7	0.0	**So**+Dp_{no}	37.6	**
pH = 6.5	2	11.2	0.0	10.4	**So**+Dp_{t}	26.2	**							13.9	0.0	0.0	**So**	13.9	*
($mmol_c\ kg^{-1}$)	3	13.6	0.0	0.8	Dp_{n}+He	34.1	***							0.0	0.9	4.4	-	0.0	*
	4	2.2	0.0	7.1	-	0.0	-							5.2	0.0	4.4	Dp_{so}+Di	35.0	**
	loc.	7.2	0.0	9.4	**So**	7.2	*							0.0	0.0	0.0	-	7.0	*
CEC pool	hum.	19.2	0.6	9.8	Dp_{nh}+Ds	43.7	***							10.8	21.3	9.8	**So**+La+Dp_{so}.So	56.6	***
($kmol_c\ ha^{-1}$)	1	26.7	2.8	18.3	**So**	26.7	**	36.8	41.1	11.6	**So**+**Dr_{c}**+Ca+Dp_{so}.So	76.6	***	0.0	0.0	0.0	-	0.0	-
	2	36.5	4.6	19.7	**So**+Dp_{t}	47.9	***	42.3	31.0	4.5	**So**+**Dr_{c}**+Dp_{so}.So+Ca	76.2	***	0.0	0.0	1.1	-	0.0	-
	3	42.8	2.4	13.5	**So**+Dp_{t}	55.0	***	46.5	20.0	1.0	**So**+**Dr_{c}**+Dp_{no}+Dp_{no}.So+Di	75.1	***	14.0	15.4	13.6	**Dr_{c}**+Dp_{no}	36.9	***
	4	45.3	1.8	16.1	**So**+Dp_{n}	50.3	***	39.7	11.5	0.0	**So**+Dp_{no}+Dp_{no}.So+Dp_{no}.Dr+Di	79.3	***	28.0	10.8	10.6	**Dr_{c}**+Di+Dp_{no}	56.3	***
	loc.	45.5	2.7	18.1	**So**+Dp_{n}	54.2	***	60.3	0.0	0.9	**So**+La+Dp_{so}.Dr+Ca	82.3	***	8.5	10.6	9.4	**Dr_{c}**+Dp_{no}	34.1	*
$f\ H_{exch.}$ (%)	hum.	36.9	3.5	23.5	**So**+Dp_{nh}+Ds	58.2	***							52.7	10.7	2.2	**So**+Ds_{w}+Dp_{t}.So	81.7	***
	1	12.2	0.0	1.0	**So**+Di+Dp_{n}.So	61.8	***	52.7	0.0	17.5	**So**+Tr+La	70.4	***	9.6	2.9	4.4	**So**+La_{2}+**Dr_{c}**	48.8	**
	2	10.8	0.0	0.0	**So**+Dp_{nh}.So+La	73.0	***	78.6	0.0	5.0	**So**+**Dr**+La+Dp_{no}.So	92.8	***	29.7	17.3	8.4	**So**+**Dr_{c}**	34.3	**
	3	13.5	0.0	0.0	**So**+Dp_{no}.So	64.2	***	25.9	0.0	5.9	**So**+La+Dp_{so}.So	56.4	**	53.6	35.0	13.1	**So**+**Dr_{c}**	58.8	***
	4	7.4	0.0	0.0	**So**	7.4	-	9.1	6.3	0.0	**So**+Dp_{so}.So	31.9	*	57.3	41.4	0.0	**So**+**Dr**+Dp_{no}+Dr_{c}.Dp_{no}	82.8	***
	loc.	17.0	0.0	0.0	**So**+Dp_{no}.So	60.0	***	45.7	0.0	3.2	**So**+Dp_{so}+Dp_{so}.So	69.1	***	60.1	42.3	9.0	**So**+**Dr**	68.6	***
$f\ Al_{exch.}$ (%)	hum.	31.1	1.9	30.4	**Tr**+Dp_{nh}+Ds	50.7	***							3.4	0.0	0.6	Dp_{so}	15.8	*
	1	7.5	0.0	5.4	**So**+Dp_{no}+Dp_{no}.So	52.0	***	34.9	0.0	18.0	**So**+**Dr**+Ca	50.8	***	0.0	10.7	12.1	**Dr**+**So**	17.4	*
	2	13.7	0.0	10.1	Dp_{t}+La+Tr	61.9	***	13.2	6.9	9.9	**So**+**Dr_{c}**+Di+Dp_{nh}.So	59.8	***	8.0	0.0	8.2	**So**+**Dr**+Dp_{no}.So+Dr_{c}.Dp	63.8	***
	3	47.4	9.5	22.1	**So**+Dp_{so}+Tr	68.0	***	0.0	23.3	17.6	**Dr_{c}**	23.5	**	2.5	0.0	13.8	**So**+Dp_{no}.So	38.5	**
	4	26.8	2.6	23.1	**So**+Dp_{t}	37.6	***	2.7	0.0	0.0	Dp_{nh}	13.9	*	11.4	0.0	23.8	Dp_{no}+Tr	53.0	***
	loc.	28.8	0.9	17.4	**So**+Dp_{so}	45.8	***	17.4	8.8	17.7	**So**+**Dr_{c}**	31.7	**	0.0	3.1	28.8	Tr	28.8	**

Table E.1 (continued)

Variable	Layer	Loess soils						Clay soils						Peat soils					
		Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.
f B.C.$_{exch}$	hum.	35.0	2.7	34.2	**So**+**Tr**	48.5	***							47.9	6.5	0.0	**So**	47.9	***
(%)	1	29.0	0.0	26.0	**So**+Dp$_t$	52.4	***	8.4	15.3	23.1	**So**+Di+Dp$_{so}$+Dp$_{so}$.So+Tr	71.4	***	6.0	15.4	10.9	**Dr**+He+Tr	46.3	***
	2	27.9	0.5	24.5	**So**+Dp$_t$	45.7	***	14.8	13.2	15.9	**So**+**Dr**$_c$+Di+Dp$_{nh}$.So+Ds	78.2	***	16.4	18.3	17.0	**So**+**Dr**+La$_2$+Tr	63.5	***
	3	34.2	8.1	27.9	**So**+Dp$_t$	51.0	***	7.2	2.9	7.7	**So**+**Dr**$_c$.Dp$_{nh}$+Ds	29.2	*	45.7	28.5	9.9	**So**+**Dr**	50.1	***
	4	39.9	3.0	34.0	**So**+Dp$_t$+Tr	66.2	***	28.9	8.9	0.0	**So**+Dp$_{so}$+**Dr**	53.8	***	41.7	28.2	2.8	**So**+**Dr**+Tr	65.5	***
	loc.	34.2	3.0	30.9	**So**+Dp$_t$+Tr+He	66.0	***	13.5	13.4	18.7	**So**+Dp$_{so}$+Di+Dp$_{so}$.So	66.6	***	31.7	27.9	14.3	**So**+**Dr**+La$_2$+Tr	70.4	***
Al$_{ox}$ content	hum.																		
(mmol$_c$ kg^{-1})	1	0.0	0.0	0.0	Ds+Dp$_{no}$+He	18.2	**	48.3	6.3	0.0	**So**+**Dr**+Di	58.2	***	4.3	15.1	1.5	**Dr**	15.1	*
	2	4.4	0.0	9.1	Ds+Dp$_{no}$+He	46.1	***	50.7	8.7	0.0	**So**+**Dr**	55.1	***	13.6	0.0	0.0	Dp$_{so}$	38.6	***
	3	9.3	2.8	13.5	Ds	22.9	**	62.3	8.7	0.0	**So**+**Dr**$_c$	63.8	***	31.9	11.2	14.1	Dp$_{so}$	54.6	***
	4	34.3	9.8	32.5	**So**	34.3	***	34.1	33.8	8.3	**So**+**Dr**$_c$+Di	67.5	***	12.6	15.3	10.0	**Dr**+Ds+Ca	37.6	**
	loc.	12.9	2.4	14.8	Ds+Dp$_{no}$+He	51.4	***	56.1	15.7	0.0	**So**+**Dr**+Di	69.8	***	8.5	0.0	0.0	Dp$_{no}$+Ds	38.0	***
Fe$_{ox}$ content	hum.																		
(mmol$_c$ kg^{-1})	1	7.0	17.2	11.9	**So**+**Dr**+Dp$_{nh}$.Dr	56.4	***	0.0	29.3	0.0	**Dr**$_c$	31.8	***	10.0	0.0	0.0	Dp$_{no}$	24.8	**
	2	5.7	7.8	11.8	**Dr**+He+Dp$_{nh}$.Dr	64.8	***	0.0	17.8	0.0	**Dr**$_c$	20.8	**	12.6	10.5	8.6	**Dr**$_c$+Dp$_{no}$	35.2	**
	3	5.4	16.5	13.3	**Dr**+Dp$_{nh}$.Dr+He	57.1	***	3.3	4.8	0.0	**So**+**Dr**$_c$	14.4	*	17.6	24.2	19.3	**So**+**Dr**$_c$	32.6	**
	4	0.3	15.2	6.8	**Dr**	15.2	**	10.4	17.2	2.9	**Dr**$_c$+He+La+Dp$_{no}$+C	65.7	***	12.8	28.4	16.9	**Dr**$_c$+Di	43.1	***
	loc.	5.5	16.8	12.4	**Dr**+Dp$_{nh}$.Dr	64.6	***	0.3	20.6	0.0	**So**+**Dr**$_c$	29.2	**	14.1	15.2	9.7	**Dr**$_c$+Dp$_{no}$	35.3	**
P$_{ox}$ content	hum.																		
(g kg^{-1})	1	0.0	0.0	24.5	Tr	24.5	**	0.0	0.0	0.0	-	0.0	-	24.1	0.0	4.9	**So**+He+Dp$_{nh}$	50.8	***
	2	0.0	0.0	22.9	Tr	22.9	**	0.0	0.0	0.0	-	0.0	-	17.3	0.0	9.9	Dp$_{no}$	51.2	***
	3	0.0	0.0	10.3	-	0.0	-	2.3	0.0	0.0	He	12.4	*	28.6	0.0	14.2	Dp$_{no}$+Tr	65.6	***
	4	0.0	0.0	2.2	Di	11.9	*	0.0	2.2	0.0	He	46.2	***	22.9	0.0	10.4	**So**+Ds+Tr	49.0	***
	loc.	0.0	0.0	16.0	-	0.0	-	0.0	0.0	0.0	He	18.8	*	26.5	0.0	9.8	Dp$_{no}$	53.2	***
P$_{ox}$/P$_{tot}$ ratio	hum.																		
(g kg^{-1})	1	0.0	0.0	15.9	-	0.0	-	0.0	8.6	7.5	**Dr**$_c$	9.9	*	22.2	0.0	10.2	**So**+Dp$_{no}$	37.0	**
	2	3.9	0.0	7.1	-	0.0	-	0.0	16.3	6.7	**Dr**$_c$	18.7	*	13.6	0.0	4.3	**So**+Dp$_{no}$	43.5	***
	3	0.0	0.0	20.4	Tr	20.4	*	0.6	0.0	0.0	He	9.7	*	15.2	0.0	5.2	He+Dp$_{nh}$+Tr	48.5	***
	4	6.9	0.0	0.0	-	0.0	-	0.0	0.0	0.0	He	42.6	***	10.2	0.0	0.8	Ds	28.8	**
	loc.	0.8	0.0	10.5	-	0.0	-	0.0	0.0	0.0	He	14.5	*	20.1	0.0	3.3	**So**+Dp$_{no}$	43.7	***

Table E.1 (continued)

Variable	Layer	Loess soils						Clay soils						Peat soils					
		Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.
$P_{ox}/(Al+Fe)_{ox}$ ratio	hum.																		
(% g kg^{-1})	1	0.0	2.7	12.5	**Dr**+Tr+Dp_{no}+He	56.1	***	0.0	11.1	0.0	**Dr_c**	11.7	*	16.0	0.0	18.5	**So**+Tr+Ca	46.0	**
	2	0.0	1.5	10.3	Dp_{no}	10.4	*	0.0	15.0	0.2	**Dr_c**	16.6	*	5.6	0.0	11.9	He+Dp_{nh}	37.8	***
	3	0.0	2.3	5.8	Dp_t	8.5	*	4.6	0.0	0.0	-	0.0	-	10.3	2.6	10.3	**So**+Dp_{no}	26.5	*
	4	0.0	0.0	4.5	Di+Dp_{no}	17.3	**	0.0	0.0	0.0	He+Dp_{so}	46.1	***	14.8	17.9	12.9	**So**+**Dr_c**+Di+Tr+Ds	73.1	***
	loc.	0.0	0.5	10.9	-	0.0	-	0.0	0.2	0.0	Dr_c.Dp_{so}	15.8	*	14.5	1.9	16.0	**So**+Tr+Ca+Dr_c.Dp_{no}	57.8	***
Al_{ox} pool	hum.																		
($kmol_c$ ha^{-1})	1	0.0	0.0	0.0	Ds	8.4	*	49.7	2.0	0.0	**So**	49.7	***	7.7	14.6	0.0	**Dr**+Dp_{no}	25.7	*
	2	4.9	0.0	9.1	Ds+Dp_{no}+He	46.6	***	51.4	1.7	0.0	**So**	51.4	***	14.6	0.0	0.0	Dp_{so}	42.6	***
	3	10.4	3.1	14.0	Ds+He+Dp_{no}	45.2	***	56.3	1.1	0.0	**So**	56.3	***	44.7	16.5	18.6	**So**+Dp_{so}	64.2	***
	4	36.3	9.8	33.3	**So**	36.3	***	27.0	23.1	5.6	**So**+**Dr**+Di	58.0	***	14.6	17.4	9.8	**Dr**+Ds+Ca	39.6	**
	loc.	23.5	4.2	23.3	Ds+Dp_{no}+He+Tr	66.1	***	51.5	10.4	0.0	**So**+**Dr**+Di	65.1	***	23.2	9.1	2.9	Dp_{so}	41.8	***
Fe_{ox} pool	hum.																		
($kmol_c$ ha^{-1})	1	8.0	16.2	11.4	**So**+**Dr**+Ds+Dp_{nh}.Dr	58.8	***	0.0	23.6	0.0	**Dr_c**	16.3	**	11.3	0.0	0.0	Dp_{no}+Ds_w	33.1	**
	2	7.9	7.2	10.5	**Dr**+He+Dp_{nh}.Dr	64.9	***	0.0	11.5	0.0	**Dr_c**	14.6	*	15.3	9.9	10.6	**Dr_c**+Dp_{no}	33.4	**
	3	6.6	15.7	13.0	**Dr**+He+Dp_{nh}.Dr	60.0	***	9.9	1.8	0.0	**So**+**Dr_c**	16.0	*	24.6	26.1	21.9	**So**+**Dr_c**	38.1	**
	4	0.9	16.1	7.3	**Dr**	16.1	**	15.9	7.9	0.3	**So**+**Dr_c**+He+La	55.1	***	14.1	28.1	16.4	**Dr_c**+Di	44.0	***
	loc.	5.0	23.7	12.0	**Dr**+Dp_{nh}.Dr+Ds	60.4	***	8.9	9.5	0.0	**So**+**Dr_c**+He+La	44.6	**	20.0	15.6	11.2	**So**+**Dr_c**	31.8	**
P_{ox} pool	hum.																		
(kg ha^{-1})	1	0.0	0.0	24.8	Tr	24.8	**	0.0	0.0	0.0	-	0.0	-	24.9	0.0	6.5	**So**+He+Dp_{nh}	50.6	***
	2	0.0	0.0	22.4	Tr	22.4	**	0.0	0.4	0.0	Dr_c.Dp_{so}	10.0	*	20.8	0.0	12.0	**So**+He+Tr+Di	54.1	***
	3	0.0	0.0	10.3	-	0.0	-	5.5	0.0	0.0	He	12.0	-	34.6	0.7	17.4	Dp_{no}+He	65.5	***
	4	0.0	0.0	2.2	Di	11.6	*	0.0	0.0	0.0	He	45.3	***	23.6	0.0	11.0	**So**	23.6	*
	loc.	0.0	0.0	15.0	-	0.0	-	0.0	0.0	0.0	He	19.2	**	26.4	0.0	9.2	Dp_{no}	48.2	***
	hum.																		
	1																		
	2																		
	3																		
	4																		
	loc.																		

Table E.1 (continued)

Variable	Layer	Loess soils						Clay soils						Peat soils					
		Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.
pH (-)	1	27.0	0.0	11.9	**So**+**Tr**+Dp_n+Dp_n.So+Di	64.7	***	27.4	7.6	20.8	**So**+**Tr**	46.1	***	0.0	17.7	12.0	**Dr**+**Tr**+Dp_t.Dr+Ds_w+**So**	77.7	***
	2	20.1	0.0	9.2	**So**+Dp_t+La	56.1	***	28.7	10.0	18.9	**So**+**Tr**	44.8	***	2.4	18.8	29.9	**Dr**+**Tr**	45.1	***
	3							13.9	5.4	2.0	**So**+**Dr**+Dp_{so}.So	62.2	***	27.1	37.2	31.4	**Dr**+**Tr**+Dp_{no}	71.8	***
	4	37.6	8.6	35.9	**So**+**Tr**+Dp_t+He	71.0	***	12.1	0.0	0.0	**So**+Dp_t+Dp_{so}	46.7	***	46.6	39.3	11.3	**Dr**+**Tr**+Ds_w+Dp_{no}+Dr_c.Dp_{no}+Di	88.5	***
	loc.	31.4	1.6	19.8	**So**+**Tr**+Dp_t+La	68.6	***	25.2	6.8	8.9	**So**+**Dr**+Dp_{so}.So	58.7	***	29.1	40.4	30.1	**Dr**+**Tr**+Dp_{no}+Di+Dr_c.Dp_{no}	81.4	***
Ca conc.	1	43.2	0.0	22.0	**So**+**Dr**+**Tr**+Ds	60.2	***	6.5	28.3	33.5	**So**+**Tr**	39.4	***	28.3	8.9	0.0	**So**+He	50.8	***
(mol_c m_{-3})	2	37.9	0.0	27.3	**So**+**Dr**+**Tr**+Ds	55.9	***	20.3	21.9	35.9	**So**+**Dr**+**Tr**	53.6	***	14.3	0.0	0.0	**So**	14.3	*
	3							7.0	34.8	20.9	**So**+**Dr**+Ds+He	59.9	***	16.6	0.0	0.0	He+Dp_{nh}	39.9	***
	4	56.4	6.1	34.4	**So**+**Dr**+**Tr**+Ds	71.8	***	0.0	22.2	16.8	**Dr**+Dp_{so}+Ds	47.5	***	25.7	0.0	3.5	**So**	25.7	*
	loc.	48.3	1.8	29.4	**So**+**Dr**+**Tr**+Ds	66.1	***	9.5	39.7	37.0	**So**+**Dr**+Di+Dp_{so}	62.8	***	17.4	0.0	0.0	**So**	17.4	*
K conc.	1	0.0	0.0	3.3	Dp_{so}+Ds+**Tr**	50.4	***	0.9	6.5	0.5	**Dr**	6.5	-	0.0	5.6	0.0	He	20.5	**
(mol_c m_{-3})	2	0.5	3.3	6.8	Ds+**Tr**	37.4	***	8.7	8.9	0.0	**So**+**Dr**+Dp_{so}.So	51.1	**	10.7	0.0	12.4	**Tr**+He	51.6	***
	3							21.6	0.0	0.0	**So**	21.6	*	18.1	0.0	19.5	**Tr**+He+Dp_n	55.7	***
	4	6.6	15.2	7.4	**Dr**+Dp_{so}+Ds	48.1	***	0.0	14.7	0.0	**Dr**	14.7	*	24.1	0.0	10.8	**So**+**Tr**+Dr_c.Dp_{no}+Di	58.9	***
	loc.	0.6	6.5	4.0	Dp_{so}+Ds+**Tr**	50.0	***	8.3	0.0	0.0	**So**+Dp_{no}.So	35.4	**	14.6	0.0	14.3	**So**+**Dr**+**Tr**+He+Ds_w+Di	66.2	***
Al conc.	1	7.0	0.0	25.5	**So**+**Dr**+**Tr**+Di	48.6	***	52.5	4.4	19.5	**So**+**Tr**	71.4	***	21.1	35.7	9.8	**Dr**	35.7	***
(mol_c m_{-3})	2	19.2	0.0	16.6	**So**+**Tr**+Dp_t	52.0	***	42.2	10.8	13.8	**So**+**Dr**+**Tr**	67.3	***	0.0	27.5	23.4	**Dr**+**Tr**	46.8	***
	3							0.9	21.7	13.0	**Dr**	21.7	*	5.3	21.0	9.1	**Dr**+**Tr**+Dp_{nh}	42.0	**
	4	7.0	4.1	32.3	**Tr**+Dp_t	48.8	***	0.7	8.8	6.7	**Dr**+Ds	23.2	*	0.0	17.1	21.9	**Dr**+**Tr**	37.5	**
	loc.	8.3	0.3	36.9	**Tr**+Dp_t	57.3	***	24.2	24.1	26.9	**So**+**Dr**+Ds	61.3	***	9.1	35.5	24.5	**Dr**+**Tr**	52.1	***
NH_4 conc.	1	0.0	0.0	4.5	Dp_{nh}+Ds+Ca	48.6	***	12.7	24.4	12.0	**So**+**Tr**	32.7	**	0.0	7.9	22.6	**Dr**+**Tr**+La_2+Ca+Di	77.5	***
(mol_c m_{-3})	2	3.9	20.7	2.9	**Dr**+Dp_t+Ds	36.9	***	6.5	11.6	14.7	**Tr**	14.7	*	0.0	0.0	29.8	**Tr**	29.8	**
	3							3.1	0.0	0.0	Ca+Di	28.5	**	0.0	0.0	21.4	**Tr**+La	47.9	***
	4	0.0	7.7	0.0	**Dr**+Ds	26.8	*	6.0	0.0	0.0	-	0.0	-	0.0	0.0	17.8	**Tr**+La+Di+Dr_c.Dp_{so}	59.4	***
	loc.	0.0	7.5	4.1	**Dr**+Dp_t+Di+Ds	43.6	***	16.8	12.9	2.7	**So**+Di	34.0	**	0.0	0.0	27.8	**Tr**+La+**Dr_c**	60.8	***
NO_3 conc.	1	9.3	0.0	1.7	**So**	9.3	*	47.3	3.6	0.0	**So**+**Tr**	57.6	***	22.1	33.2	0.7	**Dr**+Dp_{no}+Ds_w	49.3	***
(mol_c m_{-3})	2	8.3	0.0	3.2	**So**+**Dr**	13.6	*	6.7	2.6	6.7	**So**+**Tr**+Dp_{so}.So	77.6	***	35.2	46.5	4.1	**Dr**+He+Di	61.1	***
	3							5.1	5.6	2.8	La	26.8	**	36.1	39.0	5.0	**Dr**+**Tr**+He+Dp_t+He+Ds_w+Ca	84.5	***
	4	0.0	6.1	0.0	**So**+**Dr**+Dp_n.So	51.9	***	0.0	3.4	0.0	-	3.4	-	21.6	52.0	0.0	**Dr**	52.0	***
	loc.	4.0	1.9	0.0	**So**+**Dr**+Dp_n.So	41.4	**	1.3	9.4	0.6	**Dr**	9.4	-	37.4	49.6	3.9	**Dr**+Ds_w+Dp_{no}	71.0	***

Table E.1 (continued)

Variable	Layer	Loess soils						Clay soils						Peat soils					
		Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.
SO_4 conc.	1	16.5	0.5	0.0	**So**+Dp$_{so}$	37.5	***	24.1	21.7	0.0	**So**+**Dr**+Ca+Dp$_{no}$	58.3	***	8.7	1.5	0.0	**So**+**Dr**$_c$+He+Ca	38.7	**
(mol$_c$ m$_{-3}$)	2	20.0	4.0	4.4	**So**+Ds	33.5	***	0.0	13.0	0.0	**Dr**	13.0	*	9.2	0.0	0.0	**So**+Ca	19.8	-
	3							0.0	6.9	11.9	Di	12.7	**	35.8	15.6	0.0	**So**	35.8	***
	4	44.0	24.4	29.4	**So**+**Tr**+Ds+Dp$_{no}$.S	76.6	***	0.0	23.4	15.9	**Dr**+Ds+Di	46.1	****	27.3	27.2	0.0	**So**+Ds$_w$	41.7	**
	loc.	31.0	10.8	9.7	**So**+Ds+Dp$_{so}$	45.0	***	4.0	23.1	5.9	**Dr**+Di	36.9	**	30.7	20.6	0.0	**So**	30.7	**
NH_4/NO_3	1	3.7	0.0	16.2	**Tr**+Dp$_t$+Ca+He	17.0	***	29.7	21.9	8.6	**So**+**Tr**	52.3	***	33.7	17.0	7.7	**So**+**Tr**	40.5	***
ratio	2	22.5	0.0	18.0	**So**+**Tr**+Di	16.0	**	5.0	21.5	27.9	**Tr**	27.9	**	46.3	35.7	13.8	**So**+**Tr**	52.1	***
(mol mol^{-1})	3							16.5	0.0	0.0	**So**+Ca	31.0	**	54.9	47.9	13.5	**So**+**Dr**+La$_2$+Ca	84.6	***
	4	0.0	10.4	0.0	**Dr**+He	18.0	*	5.4	5.5	0.0	**So**+**Dr**	6.2	-	30.0	54.7	2.1	**Dr**+**Tr**	52.1	***
	loc.	7.4	0.0	7.3	**So**+**Dr**+Di	23.5	*	26.1	13.6	0.0	**So**+Di	33.6	**	49.1	41.3	7.8	**So**+La$_2$	71.7	***
NH_4/K ratio	1	2.2	0.2	2.5	Dp$_{nh}$+Ds+Ca	60.1	***	9.5	20.7	16.4	**So**+**Tr**	33.3	**	2.6	0.0	31.3	**Tr**+He	54.3	***
(mol mol^{-1})	2	9.6	22.9	3.2	**Dr**+Ds	38.2	***	6.7	5.7	12.7	**Tr**+La	28.7	*	7.3	0.0	29.3	**Tr**+He+Dp$_t$	59.1	***
	3							10.9	0.0	0.0	**So**+Dp$_{nh}$+Di+He	46.4	**	7.7	0.0	22.2	**Tr**+He+Dp$_t$	57.7	***
	4	5.8	22.0	0.0	**Dr**	22.0	*	9.1	0.0	0.0	**So**	9.1	-	13.2	0.0	27.2	**So**+**Tr**	40.3	**
	loc.	10.5	19.9	3.0	**Dr**+Ds+Di	47.7	***	19.6	13.6	4.3	**So**+**Tr**	25.3	*	9.9	0.0	32.6	**Tr**+He+Dp$_t$	65.1	***
Al/Ca ratio	1	23.8	0.0	47.9	**So**+**Dr**+**Tr**	58.5	***	38.8	15.4	31.6	**So**+**Tr**	67.3	***	13.9	7.5	17.8	**So**+**Dr**+La+Dp$_{no}$.So	75.1	***
(mol mol^{-1})	2	31.1	0.0	33.1	**Tr**+Dp$_t$+He	69.0	***	41.1	14.0	21.1	**So**+**Dr**+**Tr**	71.3	***	7.6	3.0	22.7	**So**+**Dr**+**Tr**+Dp$_{no}$.So	57.1	***
	3							2.0	27.5	16.6	**Dr**	27.5	**	8.8	5.9	12.7	**Tr**+Dp$_{no}$	33.6	**
	4	26.0	10.1	45.0	**So**+Dp$_t$	56.7	***	0.0	16.9	12.9	**Dr**+Ds	31.9	**	12.4	7.1	27.7	**Tr**+Dp$_{no}$	50.8	***
	loc.	30.7	4.1	52.9	**So**+**Tr**+Dp$_t$+La	82.4	***	20.3	33.5	34.8	**So**+**Dr**+**Tr**+Ds+Dp$_{so}$.So	70.5	***	13.9	9.4	25.6	**So**+**Dr**+**Tr**+Dp$_{no}$.So+Dr$_c$.Dp$_{no}$	67.2	***
Cl conc.	1	0.0	2.5	5.5	**Tr**+Ds	20.6	*	1.6	30.4	9.2	**Dr**+Dp$_{so}$+Ds+Di	63.9	***	26.3	0.0	0.0	Dp$_{no}$	46.1	***
(mol$_c$ m$_{-3}$)	2	7.0	5.4	1.0	Ds	14.0	*	0.0	16.3	4.4	**Dr**+Di	30.2	**	45.3	11.1	0.8	**So**+Dp$_{so}$	59.4	***
	3							2.8	27.5	6.2	**Dr**	27.5	**	52.0	8.5	0.0	**So**+Dp$_{so}$+Dp$_{so}$.So	72.8	***
	4	26.0	14.8	15.5	**So**+Ds	44.3	***	4.4	28.9	12.7	**Dr**	28.9	**	53.6	0.3	0.0	**So**+Dp$_{so}$+Dp$_{so}$.So	73.5	***
	loc.	9.4	10.2	4.6	**Dr**+Ds	22.0	*	2.4	31.2	11.0	**Dr**	31.2	**	49.0	3.8	0.0	**So**+Dp$_{no}$+Ds	68.2	***
pH	1	28.6	1.1	12.8	**So**+Dp$_t$	43.7	***	23.5	14.2	24.6	**So**+**Tr**	45.8	***	20.1	17.8	7.6	**Dr**+**Tr**+He	48.1	***
(Cl adjusted)	2	26.4	43.0	13.8	**So**+Dp$_t$	37.1	***	22.7	18.2	21.6	**So**+**Dr**+He+Dp$_{so}$.So	69.9	***	21.1	29.0	23.0	**Dr**+**Tr**+Dp$_{no}$	65.6	***
	3							2.8	24.5	7.4	**So**+**Dr**+Dp$_{so}$.So	56.3	***	46.4	38.6	22.2	**So**+**Tr**+Dp$_{no}$+He	81.5	***
	4	43.0	14.2	41.0	**So**+**Tr**+Dp$_{so}$.So	70.8	***	8.9	10.1	1.7	Dp$_{so}$	31.5	***	58.6	32.1	5.6	**So**+**Dr**+**Tr**+Ds$_w$	84.4	***
	loc.	35.7	6.4	21.7	**So**+**Tr**+Dp$_t$+La	68.1	***	15.0	21.8	17.7	**So**+**Dr**+Dp$_{so}$+Dp$_{so}$.S	58.4	***	47.2	38.6	21.0	**Dr**+**Tr**+Dp$_{no}$+Di+Dr$_c$.Dp$_n$	86.2	***

Table E.1 (continued)

Variable	Layer	Loess soils						Clay soils						Peat soils					
		Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.	Soil	Drain.	Spec.	Best Model	%R^2_{adj}	Sign.
Ca conc.	1	26.3	0.0	26.1	**So**+**Dr**+**Tr**+Dp$_{t}$+He	62.3	***	2.0	4.5	13.4	**Tr**	13.4	*	42.2	12.7	0.6	**So**+La$_{2}$	62.2	***
Cl adjusted	2	14.7	0.0	21.9	**Dr**+**Tr**+Dp$_{no}$+He+Di	63.3	***	14.4	0.0	3.7	**So**	14.4	*	31.0	10.2	4.3	**So**+La$_{2}$	54.0	***
(mol$_c$ m$_{-3}$)	3							17.5	2.8	0.0	**So**+**Dr**	25.0	*	19.2	1.4	0.6	**So**	19.2	*
	4	29.2	0.0	24.2	**Dr**+**Tr**+Dp$_{no}$+He	67.2	***	8.2	6.9	0.0	**So**+**Dr**	15.9	*	6.6	0.0	12.6	**Tr**+Ds$_{w}$	25.2	*
	loc.	24.4	0.0	27.2	**So**+**Dr**+**Tr**+Dp$_{t}$+He	68.6	***	20.0	2.7	0.0	**So**+**Dr**	27.5	*	27.8	5.7	1.8	**So**	27.8	**
K conc.	1	0.0	0.0	0.0	He	11.4	*	3.0	14.0	0.0	**So**+**Dr**	21.5	*	4.5	16.3	1.7	**Dr**	16.3	*
Cl adjusted	2	1.1	0.0	0.0	-	0.0	-	2.4	18.1	0.0	**Dr**$_{c}$+Dp$_{nh}$	28.9	**	9.9	12.7	1.2	**Dr**+**Tr**	21.0	*
(mol$_c$ m$_{-3}$)	3							18.6	0.0	0.0	**So**	18.6	*	0.0	3.8	10.1	**Dr**+**Tr**	17.9	*
	4	27.2	0.0	3.3	**So**+Dp$_{n}$	37.0	***	0.0	7.4	0.0	**Dr**	7.4	-	4.1	9.0	9.4	**Dr**+**Tr**+Dp$_{so}$+He	40.1	*
	loc.	13.3	1.9	0.0	Dp$_{n}$+Di	29.4	**	1.2	2.1	0.0	Dr$_{c}$.Dp$_{nh}$	10.1	*	3.1	9.9	7.2	**Dr**+**Tr**+Ds	47.8	***
Al conc.	1	11.7	0.0	13.8	**So**+**Tr**	24.5	*	38.5	16.7	25.5	**So**+**Dr**+**Tr**+Dp$_{so}$	73.6	***	44.7	36.9	10.7	**So**+**Dr**	50.7	***
Cl adjusted	2	30.3	1.3	22.9	**So**+**Tr**+Dp$_{n}$	48.3	***	31.9	17.9	15.5	**So**+**Dr**+**Tr**	66.2	***	38.0	50.1	18.8	**Dr**+**Tr**+Dp$_{no}$	75.1	***
(mol$_c$ m$_{-3}$)	3							0.7	28.1	13.6	**Dr**	28.1	**	43.0	35.4	3.9	**Dr**+Dp$_{so}$.So+Dr$_{c}$.Dp$_{so}$+**Dr**$_{c}$	73.6	***
	4	19.4	12.7	43.2	**Tr**+Dp$_{t}$	52.2	***	0.0	23.1	18.3	**Dr**+Ds	38.0	**	19.4	19.5	15.1	**Dr**+**Tr**+Dp$_{no}$	66.1	***
	loc.	24.0	9.6	48.0	**Tr**+Dp$_{t}$	58.2	***	9.2	41.4	33.2	**So**+**Dr**+**Tr**+Ds	66.8	***	44.5	43.6	19.2	**So**+**Dr**+Dp$_{so}$.So+Dp$_{so}$.Dr	82.3	***
NH_4 conc.	1	3.0	2.7	0.4	Dp$_{nh}$+Ds+Ca	52.5	***	9.2	21.0	10.5	**So**+**Tr**	24.8	*	14.2	11.6	13.6	**So**+**Dr**+**Tr**	37.4	**
Cl adjusted	2	14.1	25.2	4.7	**Dr**+Ds	37.7	***	10.8	13.3	14.9	**So**+**Tr**	22.8	*	15.7	7.1	8.9	Dp$_{no}$	35.4	***
(mol$_c$ m$_{-3}$)	3							9.3	0.0	0.0	**So**+Ca+Di	34.5	**	17.5	0.1	6.1	**So**+**Tr**	31.3	**
	4	22.7	22.2	5.9	**So**+**Dr**+Ds	37.7	***	10.5	0.0	0.0	**So**+Ca	20.3	*	26.9	0.0	2.0	**So**+**Tr**	36.3	**
	loc.	16.9	22.8	5.6	**Dr**+Ds+Dp$_{nh}$	47.8	***	24.8	10.9	0.0	**So**+Di	44.7	***	21.6	4.7	9.6	**So**+**Tr**	36.3	**
NO_3 conc.	1	1.2	0.0	0.0	**Dr**+**Tr**	10.4	*	42.1	1.0	0.0	**So**+**Dr**+**Tr**	55.5	***	18.2	27.8	2.7	**Dr**+He	35.1	**
Cl adjusted	2	0.0	3.7	0.0	**Dr**	3.7	-	7.5	0.0	0.0	He	14.1	*	31.2	41.1	8.3	**Dr**+Di+He+Ds$_{w}$	61.5	***
(mol$_c$ m$_{-3}$)	3							0.0	15.5	0.0	**Dr**+La	33.5	**	27.0	32.1	8.2	**Tr**+He+Dp$_{t}$+Di+Ds$_{w}$+Ds	80.6	***
	4	0.0	12.2	0.0	**Dr**	12.2	*	1.4	6.8	0.0	**Dr**	6.8	-	19.9	43.7	0.8	**Dr**	43.7	***
	loc.	0.0	7.2	0.0	**Dr**	7.2	*	0.0	10.1	0.0	**Dr**	10.1	*	33.2	44.3	7.0	**Dr**+He+Ds$_{w}$	61.9	***
SO_4 conc.	1	22.8	0.0	2.8	**So**+**Dr**	28.4	**	18.2	0.0	3.9	**So**+Dp$_{so}$+Di	55.7	***	23.6	3.4	0.0	**So**+Dp$_{no}$	34.2	**
Cl adjusted	2	5.2	0.0	0.0	Di	7.2	*	2.5	0.0	0.1	Di	14.5	*	44.1	18.6	0.0	**So**+Ds+Dp$_{so}$.So	70.4	***
(mol$_c$ m$_{-3}$)	3							0.0	13.4	0.0	**Dr**	13.4	*	56.8	25.1	0.0	Ds$_{w}$	68.8	***
	4	7.9	3.5	12.6	**Tr**	12.6	*	1.6	6.0	0.0	-	6.1	-	49.5	24.5	0.0	Ds$_{w}$	69.3	***
	loc.	18.3	0.0	7.0	**So**+**Dr**+**Tr**	23.5	*	2.1	5.0	0.0	Dp$_{so}$+Di	21.9	*	54.6	25.6	0.0	Ds$_{w}$	64.9	***